NASA Conference Publication 2414

NASA-CP-2414 19860014149

Space Station Workstation Technology Workshop Report

Results of a NASA workshop held at
Goddard Space Flight Center
Greenbelt, Maryland
March 19-21, 1985

NASA

NASA Conference Publication 2414

Space Station Workstation Technology Workshop Report

Karen L. Moe and Curtis Emerson
Goddard Space Flight Center
Greenbelt, Maryland

David R. Eike and Thomas B. Malone
Carlow Associates, Inc.
Fairfax, Virginia

Results of a NASA workshop held at
Goddard Space Flight Center
Greenbelt, Maryland
March 19-21, 1985

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1986

FOREWORD

This report describes the results of a workshop conducted at Goddard Space Flight Center to identify current and anticipated trends in human-machine interface technology that are relevant to the design of a user workstation for the Space Station. The format of the workshop, which involved considerable predictive license on the part of the participants, necessitates some caution in the application of this report. To this end, the authors proffer the following advice:

- The Space Station workstation, as described herein, refers to the predicted functions and capabilities of a user workstation rather than to a literal piece of hardware. This distinction is important in that some science users may prefer to tailor their own workstations from existing equipment rather than employ an "off-the-shelf" workstation. To the extent that a standard user workstation furthers the overall mission of the Space Station, one will be available through NASA. In Keeping with NASA's objective to accommodate the broadest possible user population, however, every effort will be made to support individual user workstations.
- The authors would like to remind the reader that the predictions contained in this report are just that: predictions. We had no crystal balls or omniscient ouiji boards to guide our prognostications. What we did have was a formidable collection of scientists and engineers willing to hazard their best guesses as to what the future holds for user interface technology. We have couched our predictions in time primarily to demonstrate trends in technology rather than to provide definitive estimates of the points at which specific capabilities will emerge.
- Expecting that many readers will want additional information regarding specific predictions, we have provided lists of people and organizations currently active in research in the various technology areas. These lists are not intended to be complete, or even representative enumerations of current research. Rather, they are intended to provide the reader with a point of contact through which to pursue their own interests. We apologize to all the fine researchers who could have been listed but were not.

In closing, we would like to recall the words of Robert Goddard that served as the creative touchstone during the workshop: "It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions made by the participants of the workshop, whose expertise, insights and divinations made this report possible.

Curtis Barret
Jay Costenbader
John Dalton
Joe Gitelman
Ed Lowe
Larry Novak
Dolly Perkins
Mike Rackley
Marti Szczur
Steve Tompkins
Walt Truszkowski
Doyle McDonald
Kelli Willshire
Bruce McCandless
Marianne Rudisill
Al Wetterstroem
Larry Morgan
Ev Palmer
Randy Chambers
John O'Hare
Larry Peterson
Dana Yoerger
Deborah Boehm-Davis
Randall Davis
Ray Eberts
Michael Joost
Christine Mitchell
Kent Norman
Dan Olsen
John Sibert
Harry Snyder
David Thompson
Mark Weiser
Chris Heasly
Mark Kirkpatrick
Walt Kopp
Mary Malone

Organizational affiliations of workshop participants are presented in Appendix D.

SPACE STATION WORKSTATION

TECHNOLOGY WORKSHOP

REPORT

TABLE OF CONTENTS

Title	Page

EXECUTIVE SUMMARY

On March 19-21, 1985, a workshop was conducted at Goddard Space Flight Center (GSFC) to identify current and anticipated trends in human-machine interface technology that may impact the design or operation of a Space Station workstation. The workshop was attended by recognized experts in human-machine interaction research from academia and government. This report describes the results of that workshop in four major sections: 1) Introduction, presents an overview of the Space Station program, a description of the workstation concept, and a brief outline of the workshop process; 2) Space Station Workstation Technology Workshop, provides a detailed description of the workshop process; 3) Results, describes the results of the workshop as they apply to eight broad technology areas: user interface, resource management, control language, data base systems, automatic software development, communications, simulation, and training; and 4) Implications, discusses the implications of the results of the workshop as they apply to the design of the workstation. This section emphasizes requirements for additional research and development efforts in each of the technology areas, and discusses the various roles of the workstation as implied by the results of the workshop.

The results of the workshop are significant in that they provide a unique perspective on workstation design. This perspective, which is characterized by a major emphasis on user requirements, should prove valuable to the Phase B contractors involved in the development of the Space Station Workstation. One of the more compelling results of the workshop is the recognition that no major technological breakthroughs are required to implement the workstation concept. What is required is the creative applications of existing knowledge and technology. The major results of the workshop for each of the technology areas are as follows:

User Interface

The principal prediction for the user interface involves the development of simplified, standardized interface techniques. A major element of this prediction is the User Interface Management System (UMIS). The UMIS will employ a standardized command language that will perform a two-way translation of user-system transactions into, and out of, the necessary implementation languages. The UMIS will provide a standard interface for all applications programs available to the user. This will minimize requirements for the user to learn multiple interface modes, and will reduce the probability of error when moving between applications. In addition, the UMIS will simplify communications between users and on-board mission specialists since all users will be working with a standard interface. The UMIS will have access to a variety of dialog generating tools, including an "interface author" that will use automated interview techniques

to develop rules and algorithms for conducting the human-computer dialog. This capability will allow the user to tailor the dialog technique of the system within the bounds defined by the standard command language.

Closely related to the UIMS is a multi-modal adaptive interface that will allow multiple display formats and dialog modes to be used with various hardware configurations. This capability will allow the user to design and prototype any number of display formats and dialog modes, simulate an experiment, and then select the formats and modes that are most effective. This capability should greatly increase productivity for the individual user.

Resource Management

One of the most difficult aspects of telescience will be management and coordination of the various space station resources, including equipment, time, power, on-orbit personnel, consummables and facilities. It was predicted during the workshop that an expert system will be developed that will manage the planning and tracking of resource expenditure. This system, which was designated the resource arbiter, will have both planning and tracking elements. The planning element will allocate resources to the various users by accessing a centralized resource management data base which contains information concerning the type and amount of available resources. The resource arbiter will be capable of resolving conflicts between competing users and between ground station commands and on-orbit capabilities. The tracking element will compare planned to actual expenditure rates to identify deviations. Such deviations will be reported to the user for resolution. The resource arbiter will manage resources at the space station level, whereas the local arbiter will manage resources which have been allocated to a specific user.

Control Language

It was predicted that a standard user interface language (UIL) will be developed which will allow the user to control experiment processes and equipment using slightly constrained English. Initially, the UIL will be goal-directed, functioning as a master controller capable of translating user requests into a series of parallel activities which will achieve the user's goal. Eventually, the UIL will evolve into a context-oriented command language which is capable of extracting meaning from the operational context in which a command is given. At this point, the UIL will be capable of generating code and/or selecting pre-developed modules to implement user requests.

Related to the UIL is the prediction that icons will be used to implement the command language. Icons are computer-generated images which depict machine functions in a pictorial fashion and have associated semantic and syntactic rules which allow them to represent language elements. Unlike icons in common usage today, the icons predicted for the space station era will

be animated to depict the progression of activities. In addition, the user will be able to link icons to form command strings. It is anticipated that the use of icons will greatly reduce the need for users to memorize commands.

Data Base Systems

Predictions for data base systems fell into two areas: data base language, and data management and storage. With regard to data base language, it was predicted that a common data base query language will be developed which utilizes a layered architecture to permit machine/software independence and portability. Working in concert with the UIMS, a standard query language will allow the user interface to be constant across data bases. This capability will greatly enhance user productivity when working with the various data bases accessible through the SSIS.

With regard to data management and storage, it was predicted that Space Station-era data base management systems (DBMS) will employ some level of embedded intelligence which will allow for more sophisticated search strategies and handling of unstructured data. Optical storage devices with multiple, beam-splitting read/write heads are predicted to replace present magnetic media, allowing rapid I/O and local storage in the 100 megabyte to 1 gigabyte range. These capabilities, coupled with specialized machines using dedicated DBMS architecture, will greatly facilitate the access, retrieval, manipulation and storage of the large volume of data required by the science user during planning, scheduling, conduct and analysis of an experiment.

Automatic Software Development

One of the major predictions for automatic software development is the creation of a general purpose translator which will allow the user to access, assemble and integrate a number of independent and otherwise incompatible software development tools from various commercially available programming environments. This capability will allow the user to develop, stockpile and catalog individual software modules which will then be transferred to a centralized software "library". These modules, which will vary in complexity and application from relatively simple data manipulation algorithms to complex expert system knowledge bases, will be available to other science users for retrieval and assembly into unique applications programs which support individual user requirements. It was predicted that the human-computer dialog for this capability will employ an interactive query format to develop a program attribute specification which the system will translate into a functioning program. Actual program construction will be semi-automated, with the machine selecting "off-the-shelf" modules and presenting their capabilities to the user for acceptance/rejection. Program capabilities not available off-the-shelf will be developed off-line by human programmers using semi-automated program-generating techniques.

Communications

The workstation will function as a terminal in a widely distributed, high-speed voice, video and data communcations network. The workstation will provide the user with access to other science users, a variety of data bases, and on-orbit equipment and personnel. It is predicted that fiber-optics technology will replace current transmission media allowing users to transfer data at rates from 200 to 1000 megabites per second. The network operating system will include intelligent gateways which automatically perform the "hand shake" protocols between the workstation and other elements in the network. This capability will facilitate the process by which the user configures the communications network, greatly simplifying operations and improving productivity.

Simulation

The primary non-training application of simulation projected for the workstation is as a fast-time predictor system for resource management, experiment checkout and control, and interface prototyping. The user will be able to generate a fast-time situation of an experiment in order to predict the rate of resource expenditure, and/or the amount and quality of data generated, under alternate experiment scenarios. This will allow the user to verify the experiment's design prior to the mission. This should improve the overall productivity of the Space Station system by minimizing the probability of failed experiments. In cases where the user requires real-time control of experiment equipment, the fast-time experiment simulator will permit the user to verify a planned control sequence prior to issuing the commands. This will help compensate for the 2-6 second delay anticipated for experiment control loops. The fast-time simulator will also be capable of operating in concert with the UIM's interface author for conducting rapid display prototyping to evaluate alternate display formats and dialog modes.

Training

In order to accommodate the wide diversity of backgrounds expected for science users, the workstation will have access to a variety of decision aiding, job performance aiding, simulation and user modeling capabilities which will support automatic development of embedded training programs tailored to the needs of an individual user. These programs will employ multi-media (i.e., voice, text, video and graphics), contex-oriented experiment simulations, on-line help routines and assorted tutorials designed to reflect the requirements and level of expertise of the user. One of the significant innovations predicted for the training system is the ability to construct models or profiles of the user. This capability will consist of a catalog of user characteristics, indexed by application area and user expertise,

that will allow the system to anticipate the user's training requirements. The system will modify the user model or profile as skills improve and applications change, allowing the training program to be continuously updated to meet changing user requirements.

INTRODUCTION

BACKGROUND

Purpose

The purpose of this report is to describe the GSFC Space Station Workstation Technology Workshop in terms of workshop procedures, results, and implications of these results. The overall objective of the workshop was to forecast the state-of-the-art in workstation technology for Space Station user applications. The remainder of this section briefly describes the Space Station, in general terms, the workstation concept and the workshop. The second section, The Space Station Workstation Technology Workshop, describes the procedures implemented in the planning and conduct of the workshop. The third section, Results, presents the results of the workshop, and the fourth section, Implications, describes the implications of these results.

Space Station Program

The Space Station is a multi-purpose, permanently manned facility to be initially placed in orbit in the early 1990's. The Space Station will support scientific and commercial endeavors in space, stimulate new technologies, enhance space-based operational capabilities, and in general, maintain the leadership of the U.S. in space during the 1990's and beyond.

There are a number of unique characteristics of the Space Station Program which offer the opportunity for the introduction of innovative concepts. These include: the ability to effectively use man's presence in orbit; program growth; a "customer friendly" perspective; maintainability, commonality, and test and verification concepts; and the need for increased productivity.

Concerning the "customer friendly" characteristic, a basic objective of the Space Station Program is to fulfill customer's needs. Baselined mission capabilities provided by designers will not be reduced without full consideration of the customer's requirements and the understanding of the impact of the capability reduction. NASA will provide the basic capability to handle the several customer functions seen emerging as the Space Station develops; i.e., on-board experiments; servicing of free fliers; assembly of large structures; and launch and retrieval of reusable upper stages. Space Station requirements, from a user point of view, are described below in terms of functional elements, utilization philosophy, and user requirements:

- Space Station Functional Elements
  Functional elements of the Space Station include:
  - Pressurized laboratory and habitat
  - Attached payloads

- Command, control and communication support
- Deployment, assembly and construction
- Proximity operations, including maintenance, servicing and check out of maneuverable payloads in the vicinity of the Station
- Remote maintenance, servicing, checkout, and retrieval of payloads, satellites, and platforms remote from the Station
- Payload checkout, integration and deployment
- Payload staging for earth return, including demating, preparing and storing samples and payload equipment for return to earth
- Co-orbiting platforms
- Polar platforms.

- Space Station Utilization Philosophy

  The overriding requirement of the Space Station is that it will be customer friendly. This requirement forms the basis for the utilization philosophy which will be developed as an on-going process throughout Space Station evolution. The essential elements of the utilization philosophy are that NASA will:
  - Develop an informed customer community
  - Influence Space Station capabilities with realistic requirements
  - Accommodate flexible customer schedules and use profiles
  - Provide total accommodation requirements using an operational performance envelope approach to replace the point design reference mission concept
  - Specify an evolving customer accommodation
  - Provide requirements traceability
  - Provide a forum to resolve conflicting or incompatible design, operational or utility issues
  - Establish communications between basic research, technology development, applied research, and applications communities.

- Space Station User Requirements

  Specific space station uses, and attendant requirements, are as follows:
  - Servicing, Assembly and Transportation Mode. There is a great deal of interest in servicing of free fliers from a manned element to extend the life of the spacecraft. Specific capabilities required include: resupply of propellants and other consumables (cryogens, gases, film, etc.); planned exchange of instruments; and replacement or repair of failed components. The NASA Office of Space Sciences and Applications is developing requirements for a dedicated pressurized servicing module. Additionally, there is great interest in servicing of polar platforms. Servicing of geosynchronous satellites in-situ is anticipated in the late 1990's. A demand for assembly of large structures in space is also anticipated. Finally, requirements are being developed

for geosynchronous and deep space missions in the late 1990's.

- Materials Production, Research and Development. This user requirement demands that multiple experiments/processes be in operation simultaneously, primarily in the manned element. Specific issues include: high electrical power demands; high logistics demand; constant crew attendance; rapid sample return/analysis; and chemical contamination. Production units are currently described as both attached payloads and close co-orbiting free-fliers but are likely to evolve into primarily the latter. The most stringent requirement imposed by users is for a micro-gravity environment (equal to or less than 10^{-5} g acceleration) for long, uninterrupted periods of time (hundreds of hours or more).
- Life Sciences. Life sciences will be conducted primarily in the manned element. The basic requirements are for multiple experiments in progress simultaneously, and for late pre-launch and early post-landing access to experiments. Specific capability requirements include: having plants and animals in residence for long periods to observe single- and multi-generational effects of microgravity; high electrical power demands; high data demands due to TV requirements; high logistic demands; constant crew attendance; prevention of biological and chemical contamination; large variable -g centrifuge and sled; microgravity (equal to or less than 10^{-5} g) for long uninterrupted periods to support basic plant research and manufacturing.
- Technology Development. Requirements basically include large attached structures and tethers, power and thermal systems as drivers on manned element architecture, attitude control and center of gravity control.

Space Station Workstation Concept

- Description: The concept for a Space Station workstation is envisioned as a modular, reconfigurable, expandable, general purpose, human engineered workstation for use by scientists, technologists, design and system engineers, space and ground operators, and payload users. The workstation encompasses concepts of machine independence, modularity, standardized interfaces, expert system technology, and human-machine interaction techniques. The dynamics of a reconfigurable and evolving payload complement on-board the Space Station, coupled with the requirement for on-board interaction with experiments and remote experiment control by scientific and commercial users at their facilities, place certain requirements on the user workstation:
  - Flexibility and extendability to accommodate the variety of experiments

- Access to a communication network (TDRSS)
- Access to a variety of data bases
- Commonality between flight and ground interfaces to minimize communication errors between on-board crew members and users (including common command languages).

- Workstation Objective: The primary objective of the workstation is to enable user control and monitoring of payloads, platforms and experiments.
- Workstation Users: There are three generic user groups contemplated for the Space Station customer workstation:
  - On-orbit Payload Specialists
  - Ground Operations
  - Science Operations and Analysis.
- Workstation Assumptions and Guidelines: A set of assumptions and guidelines were developed to guide workstation specification. These are as follows:
  - The workstation will facilitate the activities associated with the planning, definition, development, verification and conduct of scientific experiments and the analysis of experiment data.
  - The workstation will be developed based on user interface technology available in the early Space Station era - the early to mid 1990's.
  - The workstation will enable all Space Station experiment control activities to be performed at a ground control center.
  - The workstation will be located at the principal investigator's facility, at regional data centers, at operations control centers, or on-board the Space Station.
  - The principal workstation user is expected to be a scientist or a technician, with minimal computer programming experience.
  - The workstation will interface directly with the NASA Space/Ground network for communication capabilities, and with the Space Station Information System (SSIS) for scheduling, crew activity and ancillary data, as well as various user-developed networks.
  - When an experiment is activated, the workstation will be on-line to the extent required, up to 24 hours a day, seven days a week, for up to 90 days duration.
  - A workstation will be capable of controlling several experiments simultaneously.
  - The workstation will be designed with sufficient redundancy to ensure graceful degradation rather than abrupt termination of control capability.
  - The workstation will be able to operate independently of the on-board crew as well as in close cooperation with the on-board crew.
  - The workstation will primarily consist of standard hardware and software with provisions for incorporation of experiment-specific modules as needed.

SPACE STATION WORKSTATION TECHNOLOGY WORKSHOP OVERVIEW

Workshop Purpose

The purpose of the Space Station Workstation Technology Workshop is to identify and forecast 1990's technology developments in order to shape and guide the concepts for Space Station workstation design. GSFC will develop a machine-independent workstation design concept which will utilize these forecasts. Further, GSFC will implement a prototype system (using state-of-the-art components) to demonstrate applications of the identified technology for the science user community.

Selection of the Workshop Medium

The interactive workshop was selected as the means of acquiring workstation technology forecasts for three reasons:

- The dynamics of technology forecasting suggest that a brainstorming approach should prove especially effective.
- Convening a workshop was judged to offer the maximum payoff in terms of results in a minimum of time.
- Eliciting interactions between the research community and the NASA community was judged to have great potential for identifying technology forecasts which are realistic, reliable and relevant to the Space Station mission.

Expected Results

The planned outcome of the workshop was to forecast the 1990's technologies applicable to the Space Station customer workstation. The forecasts include a number of elements such as the following:

- A description of the forecast
- The projected schedule of significant developments at intervals of 1990, 1995, and 1999
- Predecessor or building block technologies
- Spinoff technologies, or those for which the subject technology is a building block
- Expected developers and sources, including persons and organizations currently working in specific or related areas or are likely candidates
- Special issues including other research efforts, breakthroughs, potential obstacles, and user-related issues.

Workshop Concept and Structure

The workshop was structured as a two and one-half day meeting of two different groups of participants. One group consisted of recognized academic and government experts in human-machine

interaction research. The second group was composed of NASA scientists and engineers whose particular expertise is in development of manned and unmanned space flight systems.

After an initial session wherein all participants were introduced to the Space Station and the workstation, the workstation technology forecasts were developed in a three-stage process. The first stage involved identification of potential technologies through an application of the technique of brainstorming. The participants were divided into five groups, each of which was more or less comparable in its representation of the two expert groups. The subgroups, working independently, identified potential workstation technologies for each of the workstation functions identified as design drivers. The subgroups used a model allocation of workstation capabilities to driver functions as an aid in identifying technology requirements. The brainstorming process resulted in a list of potential technologies from each subgroup.

The second stage of the forecasting process involved defining the actual forecasts for each potential technology judged by the subgroup members to be of high priority. This resulted in a set of detailed technology descriptions for each subgroup, each of which contained the information described above under Expected Results, page 5.

The third stage of the process involved synthesizing the technology forecasts across the subgroups. This was done initially by a Synthesis Committee consisting of the leaders of the subgroups and the workshop organizers, and was completed by the entire group meeting in a plenary session.

Workshop Participants

The participants, by affiliation, are listed in Table 1.

Table 1

WORKSHOP PARTICIPANTS

1.	Curtis Barret	NASA Goddard - Code 735
2.	Jay Costenbader	NASA Goddard - Code 522.2
3.	John Dalton	NASA Goddard - Code 520
4.	Curtis Emerson	NASA Goddard - Code 522.2
5.	Joe Gitelman	NASA Goddard - Code 400.6
6.	Ed Lowe	NASA Goddard - Code 501
7.	Karen Moe	NASA Goddard - Code 522.2
8.	Larry Novak	NASA Goddard - Code 635
9.	Dolly Perkins	NASA Goddard - Code 522.1
10.	Mike Rackley	NASA Goddard - Code 522.2
11.	Marti Szczur	NASA Goddard - Code 365
12.	Steve Tompkins	NASA Goddard - Code 511
13.	Walt Truszkowski	NASA Goddard - Code 522.1
14.	David Thompson	NASA Headquarters - Code SUU
15.	Doyle McDonald	NASA Headquarters - Code SUU
16.	Kelli Willshire	NASA Headquarters - Code SEM
17.	Bruce McCandless	NASA Johnson
18.	Marianne Rudisill	NASA Johnson - Code SP
19.	Al Wetterstroem	NASA Johnson - Code EF2
20.	Larry Morgan	NASA Kennedy - Code DE-DED-22
21.	Ev Palmer	NASA Ames - Stop 239-3
22.	Randy Chambers	U.S. Army Research Institute
23.	John O'Hare	Office of Naval Research - Code 442
24.	Larry Peterson	U.S. Army
25.	Dana Yoerger	Woods Hole Oceanographic Institute
26.	Deborah Boehm-Davis	George Mason University
27.	Randall Davis	University of Colorado
28.	Ray Eberts	Purdue University
29.	Michael Joost	North Carolina State University
30.	Christine Mitchell	Georgia Institute of Technology
31.	Kent Norman	University of Maryland
32.	Dan Olsen	Brigham Young University
33.	John Sibert	George Washington University
34.	Harry Snyder	Virginia Polytechnic Institute
35.	Mark Weiser	University of Maryland
36.	David Eike	Carlow Associates
37.	Chris Heasly	Carlow Associates
38.	Mark Kirkpatrick	Carlow Associates
39.	Walt Kopp	Carlow Associates
40.	Mary Malone	Carlow Associates
41.	Tom Malone	Carlow Associates

TABLE 2: WORKSTATION CAPABILITIES

Workstation Capability Area A - Communications and Tracking

A-1 Network Control

- A-1.1 Configuration - configuration of network links and nodes, including contingency operations
- A-1.2 Security - provisions for privacy and data security
- A-1.3 Teleconferencing - real time or delayed interaction among customers, operators and crew
- A-1.4 Readiness Monitoring - monitoring of communications performance and status

A-2 Message/Data Dissemination/Distribution

- A-2.1 Communications Mode Control - control of communications systems
- A-2.2 Message Transmit/Receive - control of message communication
- A-2.3 Data Dissemination - control of data distribution and routing
- A-2.4 Electronic Mail - standard message pages

A-3 Tracking and Pointing - interpretation of position and attitude angles

A-4 Communications Interface Standards - communication criteria

Workstation Capability Area B - Resource Control

B-1 On-orbit Resource Control

B-1.1 Space Systems/Experiment Operations - control of factors affecting the experiment, such as payload attitude, sensor mode, experiment power, thermal control, contamination control, structures, etc.

B-1.2 Experiment Servicing - including maintenance, resupply, replenishment, fault isolation, and inventory control

B-1.3 Direction of Mission Specialists - tasking of on-board mission specialists

B-1.4 Access to Data Storage - access to flight data file and similar on-board data bases

B-2 Ground-Based Remote Resources Control

B-2.1 Interface with SSIS, SSDS and TMIS

B-2.2 Interface with Special Data Bases and SAIS

B-3 Ground-Based Local Resources Control

B-3.1 Local Data Base Management - control of data bases colocated with the workstation

B-3.2 Memory Control - allocation and partitioning of local storage devices

B-3.3 Documentation Control - control of document update, upgrade, storage, retrieval and accession

B-3.4 Simulation and Training Control - control of simulation exercises and training sessions

Workstation Capability Area C - User Interface

C-1 Displays

- C-1.1 Real-time data display
- C-1.2 Delayed data display - non real-time data
- C-1.3 Status/ancillary data display - experiment health and housekeeping data
- C-1.4 Integrated display - management, situation or environment display
- C-1.5 Feedback display - indicating command receipt and implementation
- C-1.6 Alarm/alert display - caution and warning
- C-1.7 Decision aids - display techniques to aid decision making

C-2 Human-computer dialogues

- C-2.1 Data entry
- C-2.2 Data access/retrieval
- C-2.3 Data designation/manipulation
- C-2.4 Data edit/verification

C-3 Procedures - including operation and maintenance sequences

C-4 User Interface Language - set of software tools for a flexible but standard user interface to space station systems, payloads and platforms.

Workstation Capability Area D - Processing Tools

D-1 Input Processing Tools

- D-1.1 Message composition - construction of tools for formatted messages
- D-1.2 Command generation - tools for command development
- D-1.3 Dialogue generation - tools for human - computer interface dialogue development

D-2 Output Processing Tools

- D-2.1 Display processing - tools for formatting of displays
- D-2.2 Report processing - tools for processing of reports
- D-2.3 Computer Aiding - tools for processing system state data for monitoring health and safety

D-3 Simulation and Training Development Tools

- D-3.1 Program processing - tools for developing simulation and/or training programs
- D-3.2 Dummy data generation - tools for identifying and processing simulation data

D-4 Software Development Tools

- D-4.1 Programming - tools for program development and coding
- D-4.2 Debugging - tools for program verification
- D-4.3 Software update - tools for modifying programs

D-5 Data handling and analysis tools - techniques for data compilation, processing and analysis

D-6 Planning Aids - methods of modeling and forecasting for planning purposes

D-7 Testing aids - methods, measures, and procedures for test and evaluation

Workstation Capability Area E - Management and Quality Assurance

E-1 SSIS Interface Management

E-2 Service Assurance

- E-2.1 Performance monitoring - total system monitoring
- E-2.2 Data quality checking - data reliability/validity checks

E-3 Safing - methods to ensure that the experiment is safe

E-4 Degraded mode operations - management of contingencies

E-5 Command management - selection, implementation and verification

E-6 Resources management - expenditure rates and trends

E-7 Service accounting - costs and time expenditures for standard and special services

E-8 Record keeping - maintenance of files and reports

TABLE 3

WORKSTATION DESIGN ISSUES FOR WORKSTATION SUBSYSTEMS

<u>Control Systems</u>

- Control Authority Allocation to Human or Machine
- Supervisory Control
- Adaptive Control - Machine Learning
- Artificial Intelligence/Expert System
- Process Control
- Flight Control
- Data Management Control
- Control of Training
- Control of Simulation
- Control of Communications
- Robotics/Teleoperations Control
- Control of Tests
- Control of Report Generation/Dissemination
- Control of Logistics/Inventories
- Control of Experiment Servicing

<u>Display</u>

- Integrated Display for Status Determination
- Display Formatting
- 3-D Display
- Color Graphics
- Mixed Media Display
- Auditory vs Visual Display
- Spread Sheet Display - Schedules
- Management Displays
- Situation Displays
- Environment Displays
- Feedback Displays
- Performance Analysis Displays

- Decision Aids
- Alarms/Alerts
- Trend Data Displays
- Predictor Data Displays
- Data Quality Displays
- Diagnostics Displays
- Training Displays
- Quick Look Displays

<u>Communications</u>

- Network Access
  - Security/Privacy
  - Simulation Interface
  - Mission Scheduling
  - On-Board Support
- Network Configuration
  - Command Link Control
  - Readiness Monitoring
  - Network Representation/Display
- Communications Links
  - With Special Data Bases
  - With On-board Mission Specialists
  - With Spaceflight Tracking and Data Network (STDN) Personnel
  - With Other Users
  - With External Simulation
  - With Archives
- Service Interruption Prevention
- Service Accounting
- Report Dissemination

<u>Data Base Management</u>

- Data Storage and Retrieval
- Dummy Data Generation

- Library for
  - Display Formats
  - Commands
  - Control Laws
  - Historical Data
- Special Data Bases
  - Perishable Skills
  - Tutorials
  - Set Points
  - Trend Data
  - Test Results
  - Logistics
  - Inventory Control
  - Record Keeping
- Software - DBMS Interfaces

Data Processing

- Data Compilation
- Data Correlation
- Simulation Data Processing
- Timeline Processing
- Display Processing
- Command Heuristics
- Performance Analysis
- Training Scheduling
- Training Decisions
- Software Debug
- Test Data Analysis
- Data Quality Checks
- Data Priority Assignments
- Data Integration/Analysis
- Distributed Processing

Software

- Architecture
- Literature Search
- Simulation

- Planning/Scheduling
- Display Format Tools
- Command Generation Tools
- Command Management
- Training Software
- Measurement Software
- Control Generation Tools
- Dialogue Selection/Generation Tools
- Software Engineering Environment
- Debugging
- Test Software
- Data Storage Software
- Experiment Servicing Software
- Experiment Monitoring Heuristics
- Data Analysis Software
- Report Generation Software

<u>Language</u>

- Translation from/to Non-English
- Planning Language
- Symbolic Language
- Command Language
- Training Language
- Control Language
- Dialogue Language
- Test Language
- Data Display Language
- Report Language
- Software Development Language

<u>Procedures</u>

- Procedural Prompts
- Command Activity Sequencing
- Training Procedures
- Dialogue Development/Handling Procedures
- Software Development Procedures
- Test Procedures

- Display/Storage Criteria
- Decision Making Criteria/Aids
- Data Analysis Procedures and Criteria
- Resources Management
- Degraded Mode Operation
- Report Preparation Procedures
- Literature Search Procedures

Facilities

- Data Storage
- Tape/Disc Storage
- Hardcopy Storage
- Teleconferencing
- Electronic Mail
- Word Processing
- Display terminals
- Multi-terminals
- I/O Devices
- Training Facilities
- Special Controllers
- Documentation Control
- Software Development Facilities

THE SPACE STATION WORKSTATION TECHNOLOGY WORKSHOP

The Space Station Workstation Technology Workshop was one step in the research and development process which will produce a prototype workstation system. The role of the workshop in this process was to provide predictions on workstation technologies expected to be available in the time frame in which workstation systems will be developed. The workstation system contains all the hardware, software, procedures, information and personnel required to meet the primary objective of the system, to serve as interface between the Space Station user and the Space Station experiment. The workshop was designed to provide insights on technology developments to support the workstation system design at two different levels: the elemental, subsystem level of building block technology; and the system level, wherein the elements must be integrated into a coherent whole. It was in this context that the requirement for the Space Station Workstation Technology Workshop was estabnlished. The procedures for conducting the workshop are discussed in this section in terms of four major phases: workshop planning, workshop development, workshop conduct, and workshop data analysis and interpretration.

WORKSHOP PLANNING

This section describes the steps followed in the planning of the workshop. These included identification of workstation technology issues, space station and workstation requirements, workstation functions, workstation capabilities and workstation design requirements.

Workstation Technology Issues

The initial activity in this effort entailed the identification of generic workstation design issues. These issues, which are listed in Appendix A, comprise an identification of hardware and software concerns for an advanced workstation, irrespective of its intended application.

Space Station Requirements

Space Station requirements expected to influence the conceptualization of the workstation were identified. The major source of these requirements was the Space Station Phase B Request for Proposal. The requirements are presented in Appendix B.

Workstation Requirements

Requirements for the workstation were developed for a set of generic workstation operations. These operations were:

- Mission planning
- Crew activity interface
- Scientific data handling
- Status data handling
- Management data handling
- Ancillary data handling
- Command and control
- Communications and tracking
- Maintenance and logistics
- Software development
- Simulation and training

Workstation requirements for each of the operations were as follows:

- Scientific Data Handling
  - The workstation will provide all required capability to receive, select, process, store, communicate, disseminate, analyze, and interpret scientific data.
  - The workstation will meet to-be-established data quality standards to ensure maximum levels of data reliability and data validity.
  - The workstation will provide direct access to selected special data bases of scientific data.
- Status Data Handling
  - The workstation will continually acquire and process housekeeping data to determine the status of the experiment.
  - The workstation will acquire and process diagnostic data to enable the isolation of problems and determination of solutions.
  - The workstation will develop and process early warning indications that experiment operation will be degraded at a specified time in the future.
- Management Data Handling
  - The workstation will support formulation of decisions concerning experiment configuration, initiation, modification and termination.
- Ancillary Data Handling
  - The workstation will acquire, process and analyze data on: experiment conditions, environments, missions and operations; crew activities and utililzation schedules; and space station systems, equipment and facilities.
- Command and Control
  - The workstation will develop, process and implement all experiment commands or procedures and control inputs, including direction to the on-board crew to implement control activities.
  - The workstation will maintain a library of predeveloped commands for immediate implementation.
  - The workstation will include command generation tools for on-line command development or modification.
  - The workstation will develop and implement experiment control rules.

  - The workstation will enable a range of control authority modes, including completely manual, supervisory, adaptive, and intelligent machine control.
- Software Development
  - The workstation will enable creation of new software, verification of developed software, and modification of existing software.
  - The workstation will maintain a library of already developed software modules.
- Communications and Tracking
  - The workstation will maintain real time communications with the experiment as needed.
  - The workstation will communicate with network control elements as needed.
  - Communications capabilities will be provided for the communication of voice, digitized data, analog data, video, pictorials, graphics, text and symbols, as needed.
  - The workstation will be capable fo communicating with centralized tracking facilities to receive experiment-related tracking data.
- Simulation and Training
  - The workstation will provide the capability to conduct full-mission simulations or part-task simulations of experiment operations.
  - The workstation will be capable of interfacing with network simulation facilities.
  - The workstation will enable experiment operations training either on-line or off-line.
- Maintenance and Logistics
  - The workstation will enable remote servicing of the experiment, including resupply, refurbishment, replenishment, instrument exchange, checkout, calibration, repair, inspection, deployment, and assembly/disassembly.
  - The workstation will provide for continual automated test and monitoring of the experiment.
  - The workstation will provide for continual automated test and monitoring of the experiment.
  - The workstation will maintain control over experiment logistics, including spaces, resupply, tools, test kits, etc.
- Crew Activity Interface
  - The workstation will maintain or have access to an up-to-date determination of current and projected crewmember availability.
  - The workstation will maintain or have access to data files on crewman special skills and space station resources, such as EVA.
- Mission Planning
  - The workstation will support experiment planning and scheduling.
  - The workstation will have direct access to mission planning and scheduling.

Workstation Functions

Based on the requirements by operations, top level functions were developed for five major phases of scientific experiment implementation:

- Experiment definiation
- Experiment development
- Experiment test and integration
- Experiment conduct
- Experiment data analysis.

For each of these phases, a sequence of functions was developed as depicted in Figures 1 through 5. These functions were then examined to determine which were important for the design of the workstation. Those selected were designated as workstation design drivers and are highlighted in Figures 1 through 5.

Workstation Design Requirement

For each function identified in Figures 1 through 5, a set of design requirements was developed.

Workstation Capabilities

Based on workstation requirements, a set of required workstation capabilities was identified as required to enable the completion of the driver fucntions. The capability areas are described in Table 2.

Workstation Design Issues

Design issues were identified for each of specified workstation subsystems, which include:

- Control system
- Displays
- Communications
- Database management
- Data processing
- Software
- Language
- Procedures
- Facilities

The design issues for each subsystem are identified in Table 3.

WORKSHOP DEVELOPMENT

In the development of the workshop, three topics are relevant: workshop participant selection, technology forecast process, and group leader preparation.

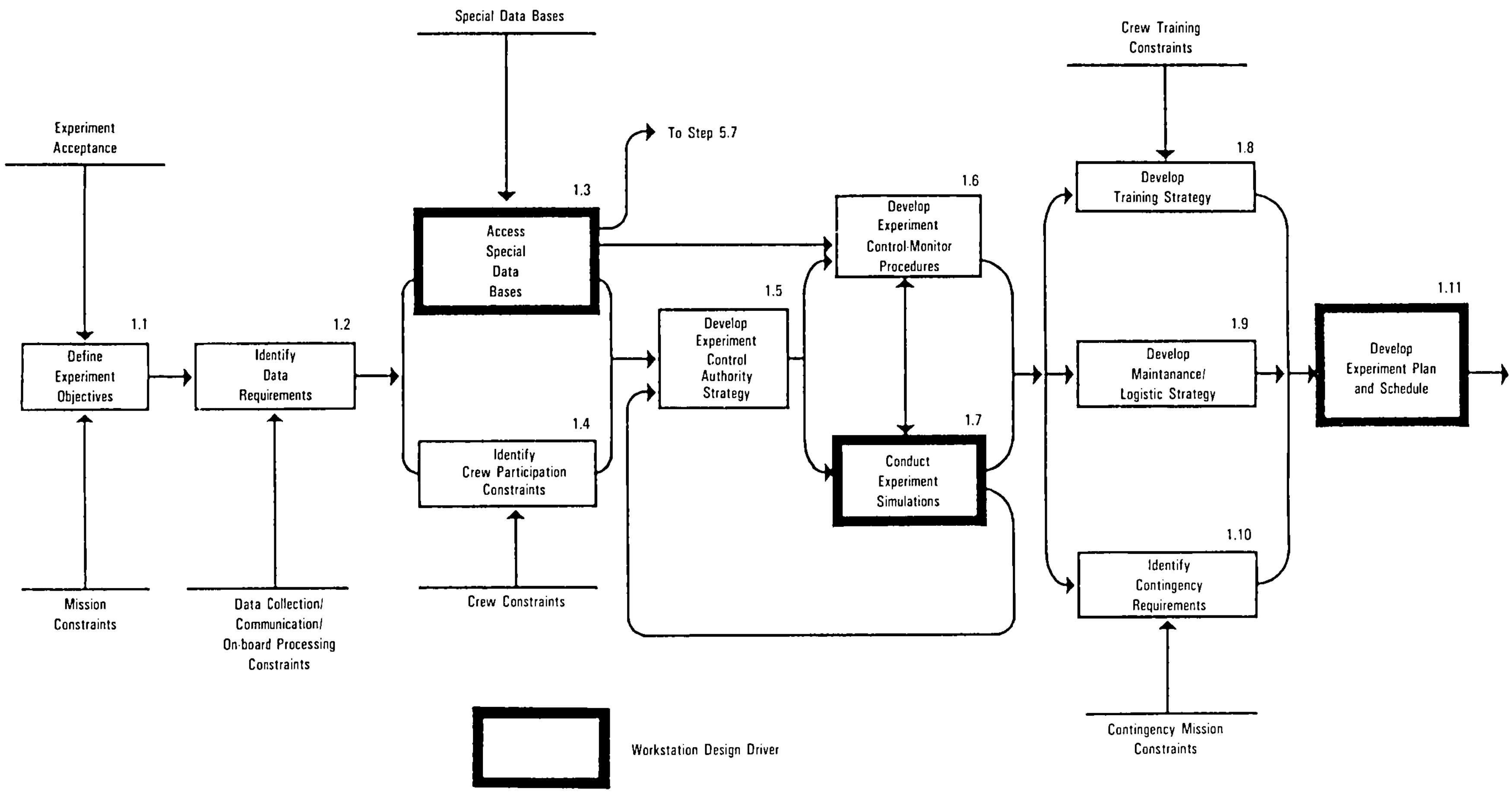

Figure 1. First Level Functional Flow for Function 1.0 Experiment Definition

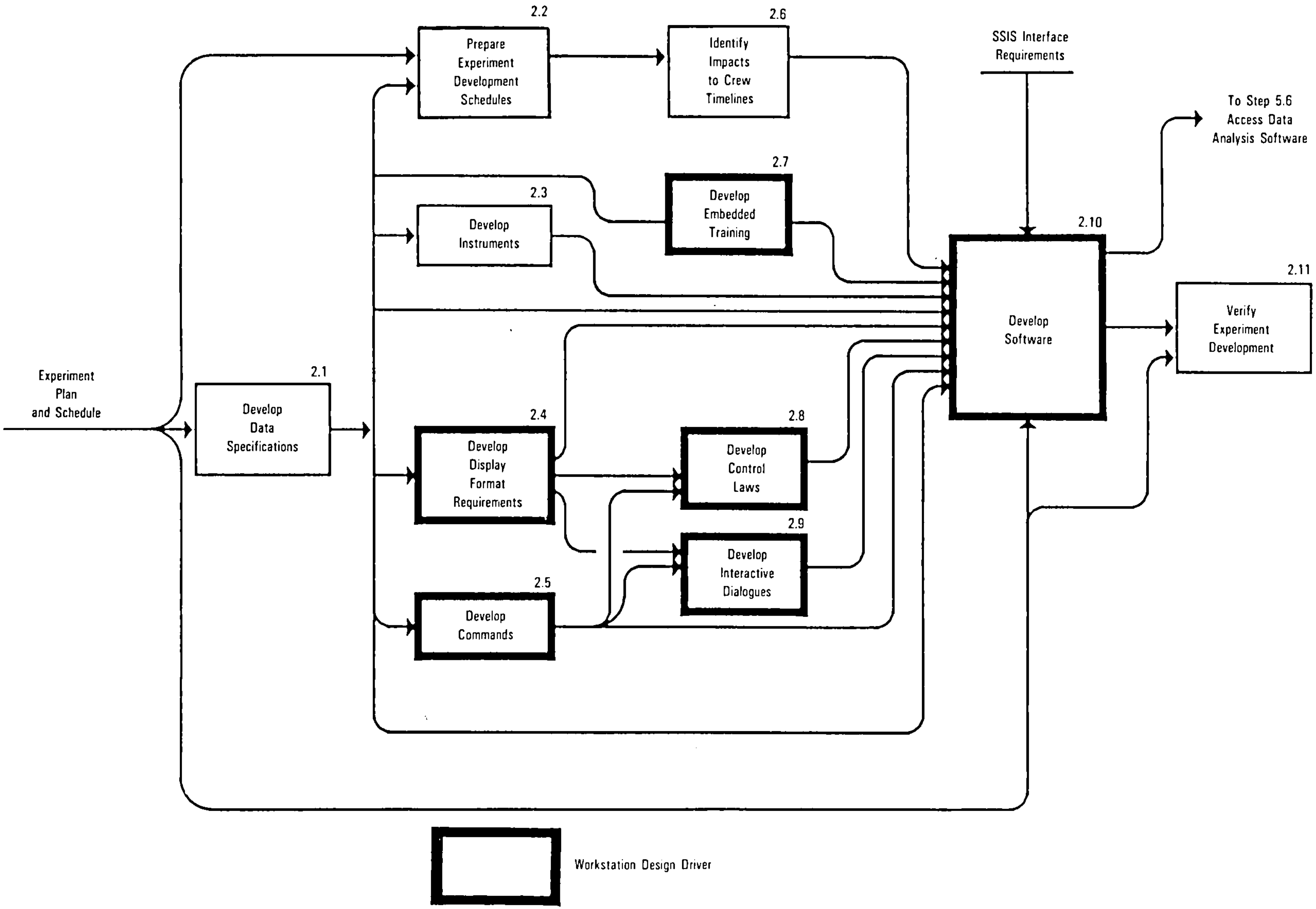

Figure 2. First Level Functional Flow for Function 2.0 Experiment Development

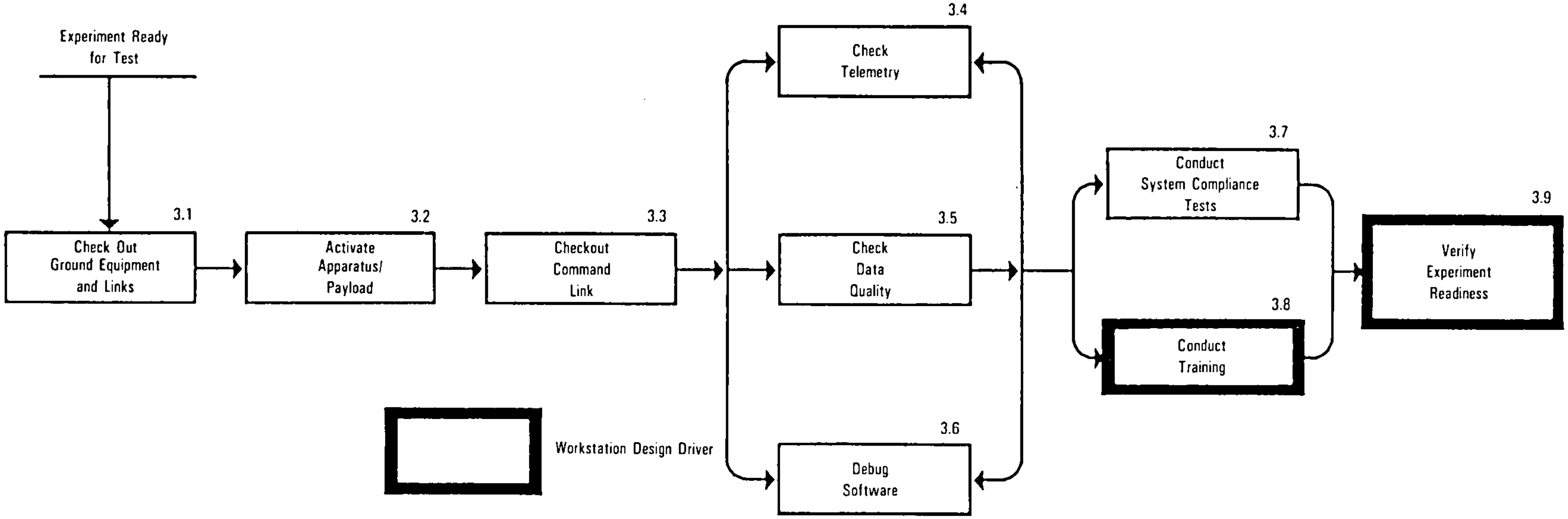

Figure 3. First Level Functional Flow for Function 3.0 Experiment Test and Integration

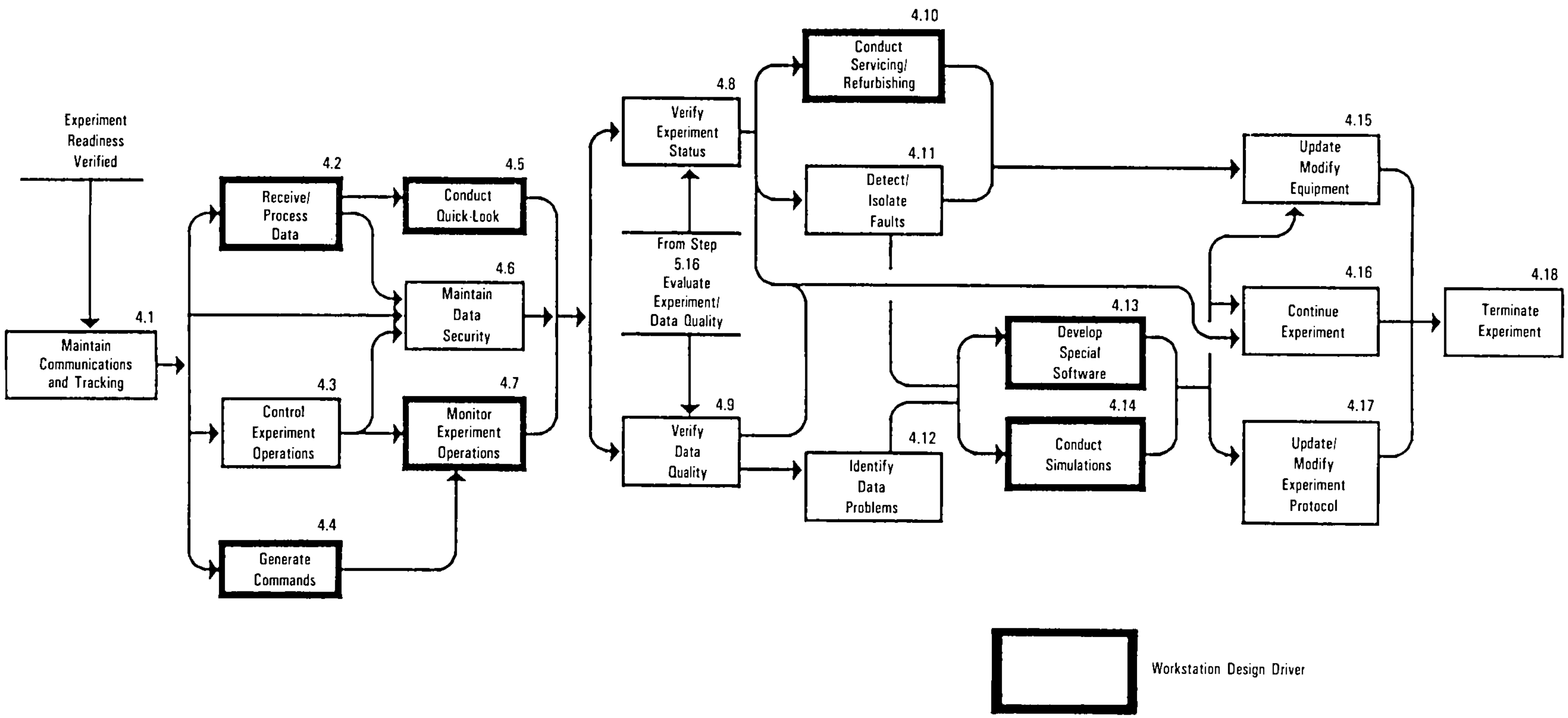

Figure 4. First Level Functional Flow for Function 4.0 Conduct Experiment On-Orbit

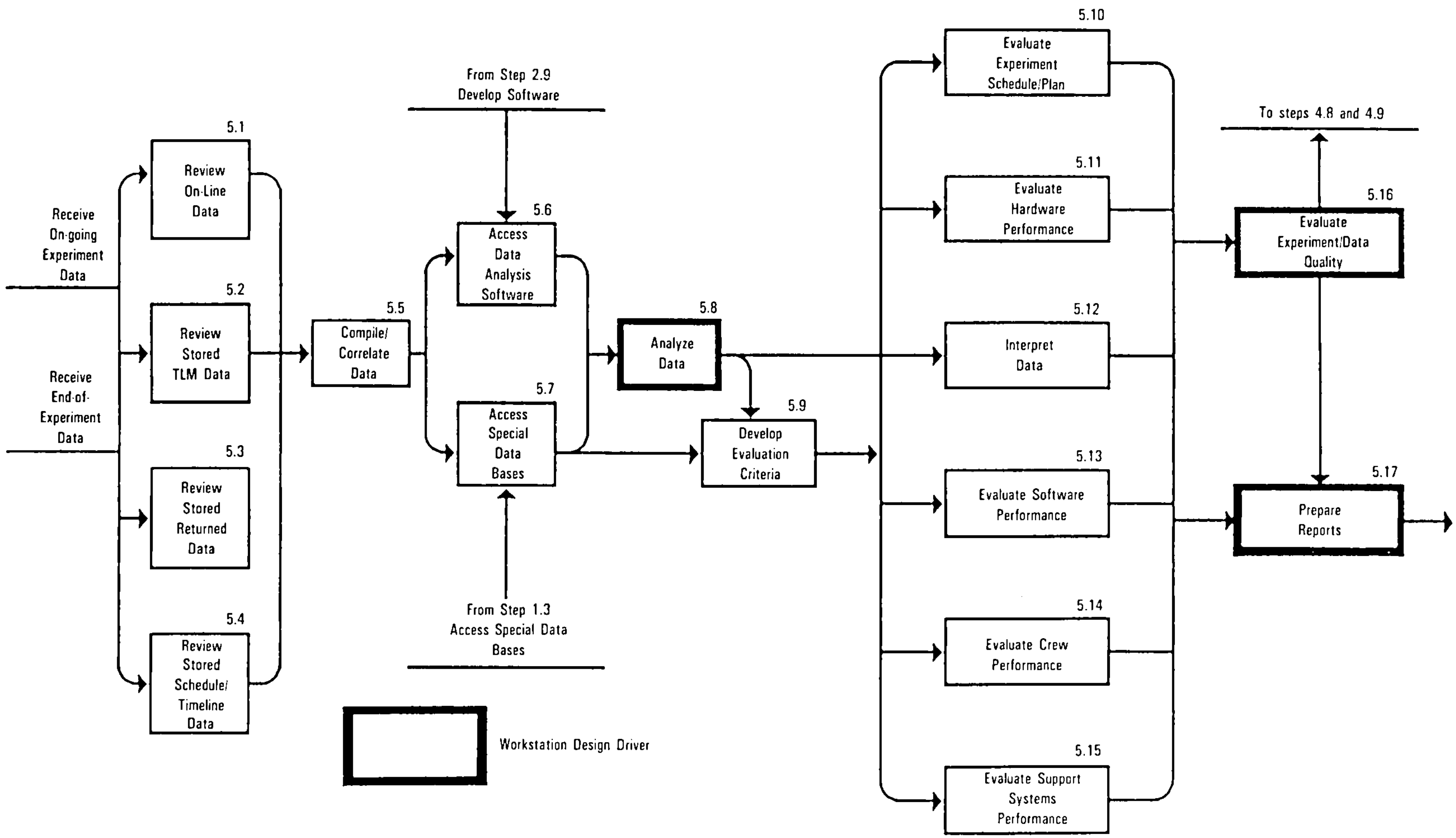

Figure 5. First Level Functional Flow for Function 5.0 Experiment Evaluation/Data Analysis

Workshop Participant Selection

Potential participants in the workshop were selected from two populations:

- Those from government agencies, including NASA, and academia, with expertise in human-computer interfaces
- Those from NASA with expertise in space flight systems in general, and Space Station in particular.

Each participant was asked to complete a technology familiarity profile denoting his or her degree of experience with technology areas associated with workstation design (Figure 6). Responses to this profile were used to assign participants to working groups.

Techonology Forecast Process

The process of technology forecasting is depicted in Figure 7. As indicated in the figure, technology forecasts were made based on workstation functions and capabilities. The worksheets that were sent to participants in advance of the workshop, and which required them to identify potential technology forecasts, are presented in Appendix C.

Group Leader Preparation

The group leaders were provided guidelines for technology forecasting in an all-day meeting at GSFC. This meeting produced example technology forecast areas such as those presented in Table 4.

WORKSHOP CONDUCT

This section describes the procedures employed in the actual conduct of the workstation technology workshop. The agenda for the workshop is presented in Table 5.

Orientation

The workshop began with an orientation session. Ms. Karen L. Moe, the workshop General Chair, opened the session with an introduction to the workstation concept. Mr. John T. Dalton, Chief of the GSFC Data Systems Technology Division, welcomed the participants and placed the workshop in the context of the Space Station Program in general, and the Space Station Program at Goddard Space Flight Center in particular.

Ms. Moe discussed the objective and scope of the workshop, reviewed the schedule and described the anticipated results. She then introduced Dr. David E. Thompson, Chairman of the NASA Science and Applications Advocacy Group.

Dr. Thompson presented an overview of the status of Space Station planning within NASA emphasizing the types of science and application missions anticipated. Ms. Moe then presented

WORKSHOP PARTICIPANT PROFILE

Name: ______________________________

Affiliation: ______________________________

Title: ______________________________

Experience Rating (Rate each item on a 5 point scale with 1 indicating minimal experience and 5 meaning extensive experience)

Technology Area	Rating	Comment
• Input Devices	____	
• Displays		
- integrated displays	____	
- Large screen displays	____	
- advanced techniques	____	
• Data Storage Technique	____	
• Memory Management	____	
• Communications	____	
• Networks	____	
• Distributed Processing	____	
• Display Processing	____	
• Human-computer dialogues	____	
• Command Language	____	
• Graphics	____	
• Machine Intelligence	____	
• System Integration	____	
• Office Automation	____	
• Software Engineering	____	
• Embedded Training	____	
• Human-Computer Interface		
- test and evaluation	____	
• Voice Input and/or Output	____	
• Teleconferencing	____	
• Robotics	____	
• Intelligent Terminals	____	
• Data Access Techniques	____	
• Decision Aiding	____	

Areas of my involvement in human-computer interface technology development/application not listed above are as follows:

Figure 6

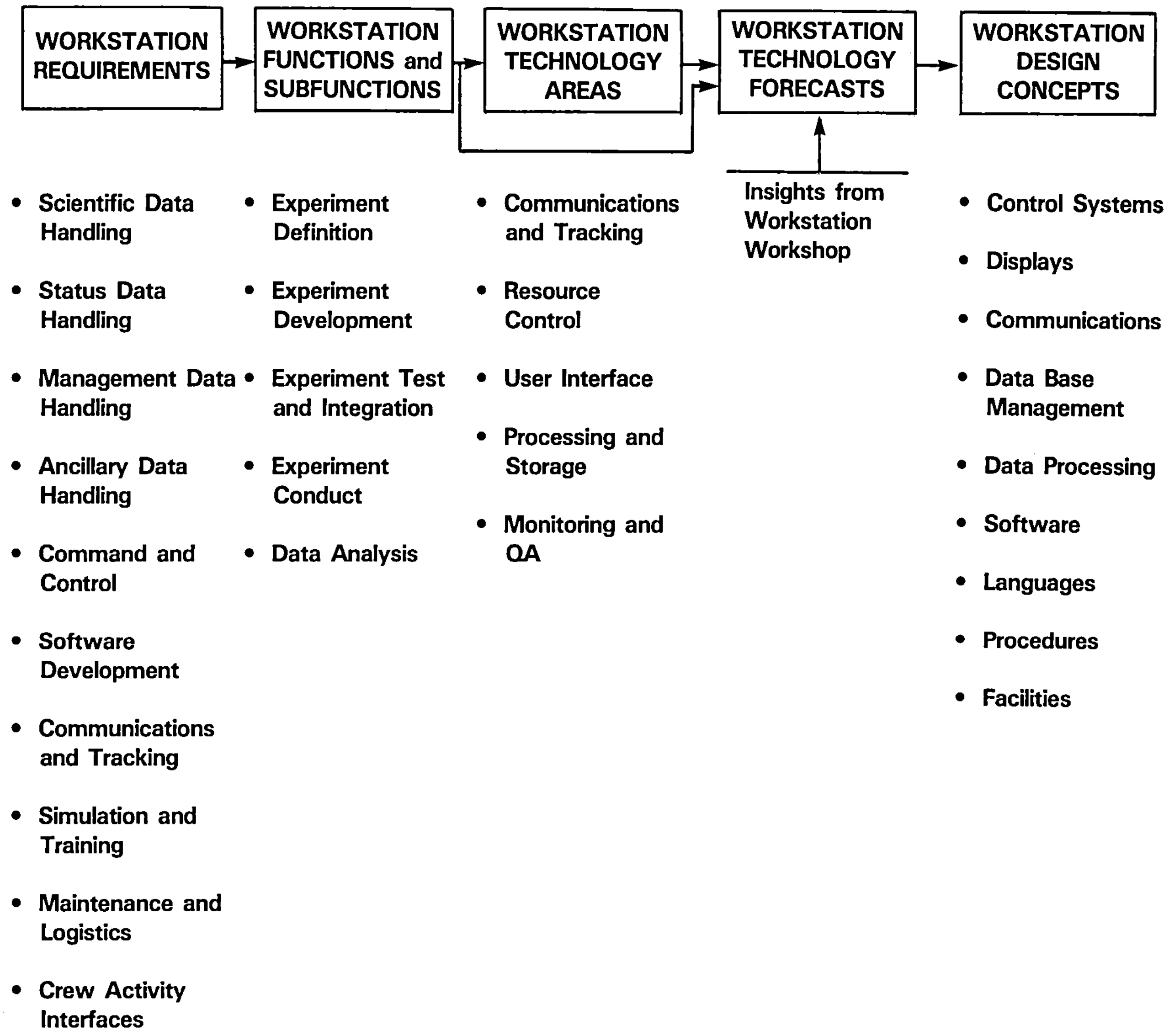

Figure 7. Technology Forecasting Process

Table 4

EXAMPLE TECHNOLOGY FORECAST AREAS

A. COMMUNICATION

- Teleconference
- Telepresence
- Electronic mail
- Esperanza
- Expert system translator
- Fiber optics
- Cryptography
- Voice print access
- Gateways

B. RESOURCE CONTROL

- Robotics
  - Sensing robots
  - AI - machine learning/ expert systems
  - Teleoperators

C. USER INTERFACE

- 3-dimensional laser-generated displays
- LCDs
- CRTs
- Plasma screens
- Flat screens
- Holography
- Micro TV
- Voice
  - Recognition
  - Generation/synthesis
  - Text-to-voice/voice-to-text
- Laser printers
- Input devices
  - Touch screens
  - Mice
  - Trackballs/joysticks
  - Light pens
  - Digitizing tablets
  - Keyboards
    - Dvorak
    - 2-handed (Klockenberg)
- Natural command languages
  - Parsing
- Large screen displays
- Windowing

D. PROCESSING/STORAGE

- Bubble memory
- Laser discs
  - Compact discs
- Microfiche
- DBMS techniques
- AI
  - Expert Systems
- Josephson junctions
- Parallel CPUs
  - (Fifth generation)
- Image processing
- Transphasors
  - (optical transistors)
- N-MOS/C-MOS
- Symbol manipulation

E. MONITORING AND QA

- Cameras
  - cctv
  - low light tv
- Acoustic microscopy
  - Scanning Laser Acoustic Microscope (SLAM)
- Scanning electron microscopes
- Image processing
  - Machine vision
- Other machine sensing

Table 5

WORKSHOP OVERALL SCHEDULE

Day 1 AM Session Building 3, Room 200		
0800 - 0900	Introductory Remarks	Moe
	Welcome	Dalton
	Review of Schedule	Moe
	Review of Objective and Scope	
	Review of Anticipated Results	
0900 - 0930	Space Station Overview	Thompson
0930 - 1000	Role of Ground-based Workstation	Moe
1000 - 1015	Break	
1015 - 1130	Workstation Design Concept	Moe
1130 - 1200	Workshop Process - Overview	Eike
1200 - 1300	Lunch, Building 21	
Day 1 PM Session Building 26, Room 205		
1300 - 1700	Parallel Sessions- Brainstorming	All
1900 -	No Host Dinner - Holiday Inn	All Interested
Day 2 Building 26, Room 205		
0800 - 1200	Parallel Sessions - Forecasting	All
1200 - 1300	Lunch	
1300 - 1700	Parallel Sessions - Forecasting	All
1830 - 2230	Synthesis of Technology Forecasts	Group Leaders
Day 3 Building 23, Room S308		
0800 - 1130	Synthesis of Technology Forecasts	All
1130 - 1200	Summary and Wrap-up	Moe

an overview of the role of the workstation within the Space Station Program. She identified potential interfaces between Space Station users and Space Station elements, as depicted in Figure 8, and described the workstation design concept as illustrated in Figure 9.

Mr. David R. Eike, the Program Manager of the Workshop Development Task for Carlow Associates Incorporated, discussed the role of the workshop in workstation development. He presented an overview of the workstation technology forecast process which is contained in Figure 10. As stated earlier, workstation technology forecasts were developed in a three-stage process:

- brainstorming to identify projected technology developments which may have application for the Space Station Workstation;
- actual forecasting which involved describing in greater detail, those projected technology developments judged to be especially meaningful for the Space Station Workstation; and
- summarizing or synthesizing of the forecasts to enable the identification of technology development requirements.

The forecast process then continued over the next two days.

Team Structure

The group of workshop participants was segmented into five teams of roughly the same size and expertise composition. The assignments to teams are presented in Table 6. Besides the participants, each team was composed of a team leader and a recorder. Duties of each team member are described for each stage of the forecast process.

Brainstorming

The roles and responsibilities of the team leader, the recorder, and participants are presented below.

- Team Leader: In the brainstorming session the team leader performed the following functions:
  - Elicited technology forecast ideas from team participants
  - Prompted the team participants with example technology developments for each workstation function
  - Posted identified technology ideas on a tote board classified by technology area
  - Ensured that the recorder was capturing important data
  - Achieved consensus of the team as to which technology area a specific idea should be assigned
  - Achieved consensus of the team concerning the relative priority of each technology idea in terms of its importance to the workstation development effort.
- Recorder: The duties of the recorder in the brainstorming session included the following:
  - Recorded identified technology ideas on a technology tally sheet (Figure 11)

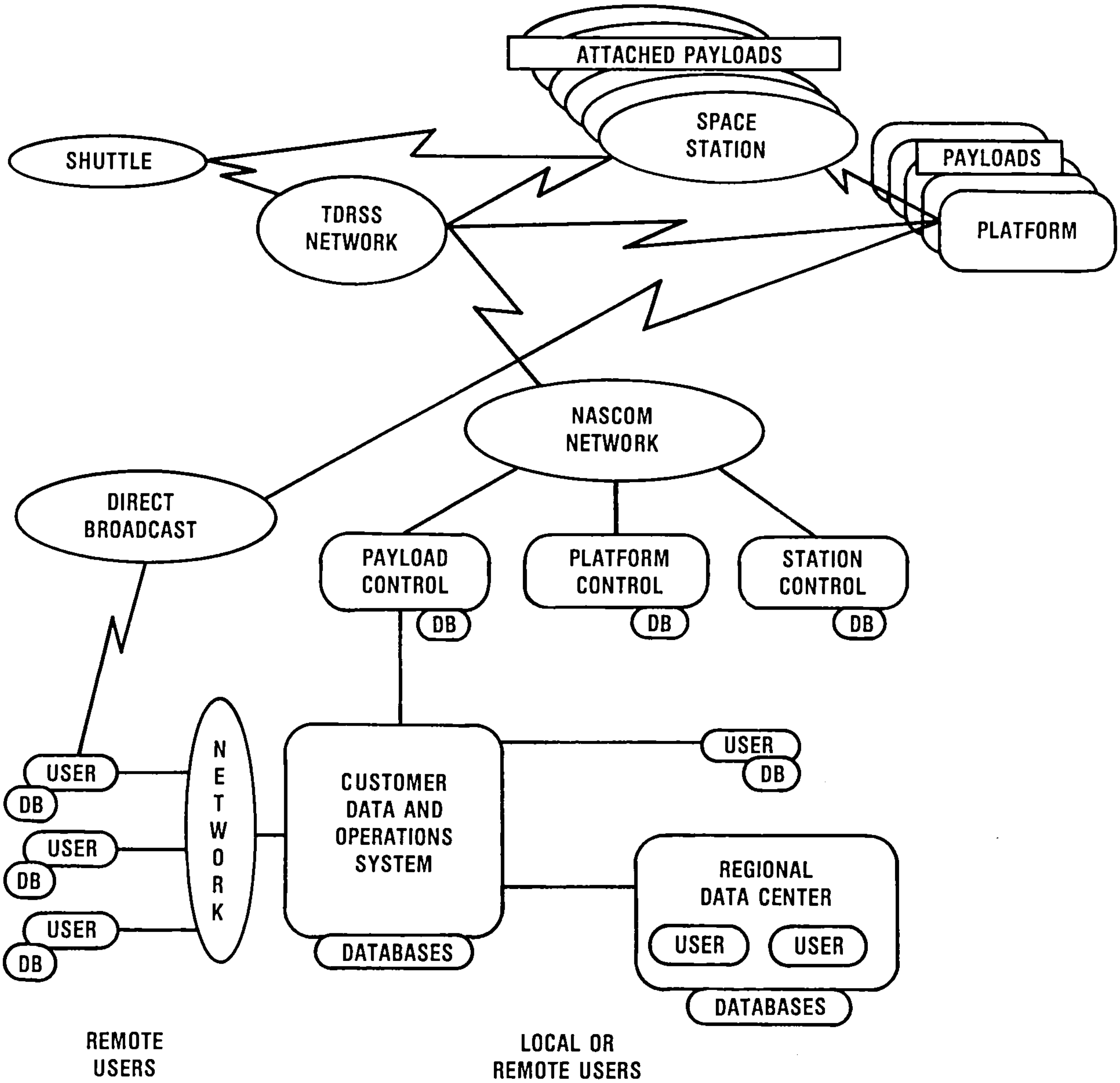

Figure 8. Potential Space Station Operational Interfaces

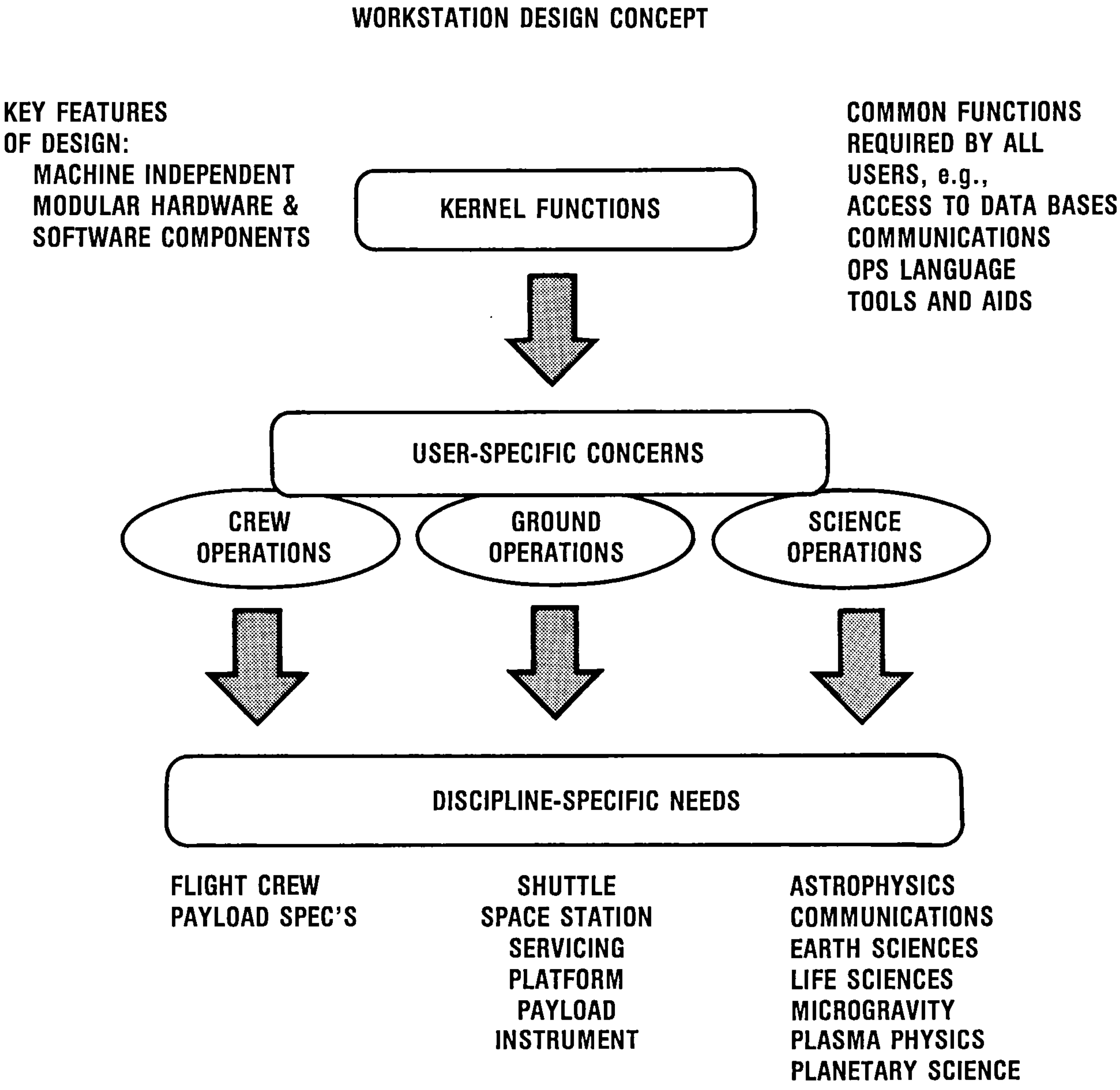

Figure 9. Workstation Design Concept

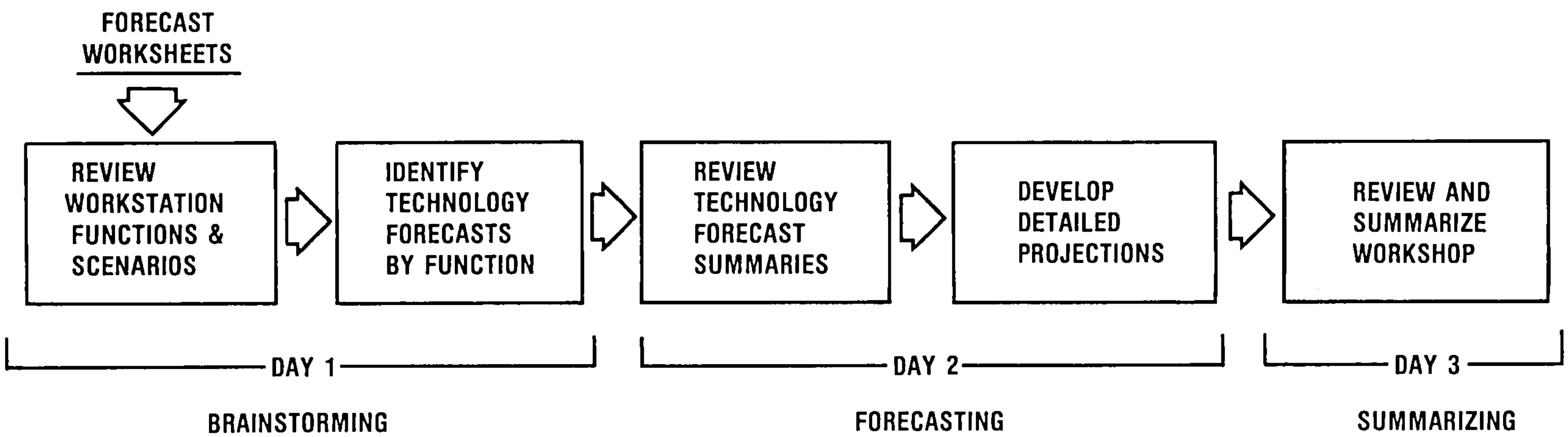

Figure 10. Forecast Process Overview

Table 6

TEAM ASSIGNMENTS

BLUE GROUP

GROUP LEADER: Marti Szczur

Recorder: Curtis Emerson

Group Members: Randall Davis
Dan Olsen
Dana Yoerger
B.J. Bluth
Joe Gitelman
Al Wetterstroem

YELLOW GROUP

GROUP LEADER: Larry Novak

Recorder: Walt Kopp

Group Members: Mark Weiser
Deborah Boehm-Davis
Randy Chambers
Marianne Rudisill
Larry Morgan
Curtis Barrett

GREEN GROUP

GROUP LEADER: Dolly Perkins

Recorder: Chris Heasly

Group Members: Kent Norman
Walt Truszkowski
Larry Peterson
Doyle McDonald
Bruce McCandless
Ray Eberts

RED GROUP

GROUP LEADER: Ed Lowe

Recorder: Mike Rackley

Group Members: Christine Mitchell
Michael Joost
John O'Hare
Mel Montemerlo
C.W. Vowell

BLACK GROUP

GROUP LEADER: Mark Kirkpatrick

Recorder: Jay Costenbader

Group Members: John Sibert
Harry Snyder
Kelli Willshire
Ev Palmer
Steve Tompkins

Tech Area ______

Group ________ Page ____ of ____

Technology Tally Sheet

		Data Base Access	EXPMT Simulations	EXPMT Plan/Schedule	Display Formats	Command Develop.	Training Develop.	Control Laws Develop.	Inter. Dialogue Dev.	Software Develop.	Conduct Training	Verify Readiness	Receive-Process Data	Generate commands	Conduct Quick Look	Monitor Operations	Conduct Servicing	Spec. Software Develop.	Conduct Simulations	Analyze Data	Eval. Expmt-Data	Prepare Reports	
Code	Technology Forecast	1.3	1.7	1.11	2.4	2.5	2.7	2.8	2.9	2.10	3.8	3.9	4.2	4.4	4.5	4.7	4.10	4.13	4.14	5.8	5.16	5.17	Priority

Technology Area Key: A - Communication B - Resource control C - User Interface D - Processing/Storage E - Monitoring/QA

Technology Priority Key: H - High (important for the subfunction) M - Moderate L - Low X - To be determined

Figure 11

- Assigned a code to each technology idea
- Recorded the priority rating assigned to each technology idea for each driver function as High, Moderate, or Low
- Recorded the overall priority of each technology idea as assigned by the team members.

- Team Members: The roles and responsibilities of the team members during the brainstorming process were as follows:
  - Identified technology ideas for each driver function, using as a guide, the worksheets provided to them prior to the workshop which contained the workstation capabilities assigned to each function (Appendix D)
  - Identified a technology area for each technology idea from those listed in Figure 12
  - Assigned a priority rating to each technology idea for each driver function
  - Assigned an overall priority rating to each technology idea.

Forecasting

The forecasting process involved reviewing the technology ideas generated in the brainstorming session and developing detailed technology projections for the ideas receiving a high priority rating. Roles of the team elements are discussed below.

- Team Leader: specific duties assigned to the team leader in the forecasting session were:
  - Led a discussion of each selected technology idea to generate a description of the technology
  - Elicit from the team an estimate of when the technology is expected to be available
  - Provided technology forecast records to the synthesis committee.
- Recorder: Duties of the recorder were:
  - Recorded technology forecast data on the technology forecast record (Figure 13)
  - Updated the technology tally sheets with new technologies not identified in the brainstorming session.
- Team Members: actions performed by team members during the forecasting session were as follows:
  - Developed a description of each selected technology
  - Developed a forecast for each technology as to how well developed the technology is expected to be in the years 1990, 1995 and 1999
  - Identified potential technology developers and information sources based on an understanding of which organizations and individuals are currently involved in technology development in related areas
  - Identified predecessor technologies which will serve as building blocks for the development of the identified technology
  - Identified spinoff technologies, or items for which this technology is a building block

TECHNOLOGY AREA	CHARACTERISTICS
COMMUNICATIONS	Equipment, software and procedures required to connect the workstation with other ground, orbiting and free-flying elements
RESOURCE CONTROL	Equipment, software and procedures used to control experiment-related resources (local, remote and on-orbit)
USER INTERFACE	Equipment, software and procedures that provide workstation input and output capability
PROCESSING AND STORAGE	Equipment, software and procedures used to process, store, access and retrieve information
MONITORING AND QA	Equipment, software and procedures used to monitor parameters related to mission success

Figure 12. Technology Areas

GROUP ____________ AREA CODE ____________

TECHNOLOGY FORECAST RECORD

TECHNOLOGY DESCRIPTION: ____

____

____

____

FORECAST: 1990 ____

____

____

1995 ____

____

____

1999 ____

____

____

EXPECTED DEVELOPERS/SOURCES: ____

____

____

PREDECESSOR TECHNOLOGIES (AREA CODES) : ____________________________

SPINOFF TECHNOLOGIES (AREA CODES) : ____________________________

LEVEL OF EFFORT:

_______ Low (within current state-of-art)

_______ Moderate (additional research required)

_______ High (major breakthrough required)

SPECIAL ISSUES:

Figure 13. Technology Forecast Record

- Identified the level of effort expected in developing the technology as High, Moderate or Low
- Identified special issues associated with the technology such as breakthroughs required, expected problems or obstacles, and user-related issues such as needs for special training, operator aids, hazards, etc.

Summarizing

In the summarizing/synthesizing session, the team leaders, the Synthesis Committee, and the total workshop group participated. The specific roles of each were:

- Team Leaders
  - Served as members of the Synthesis Committee
  - Led the summary session discussion by all participants of technology forecasts developed in the forecasting session.
- Synthesis Committee: composed of the team leaders and workshop organizers, this committee reviewed the technology forecast records submitted by each team and synthesized technology forecasts across the teams. Specific duties of the committee were as follows:
  - Resolved inconsistencies and conflicts in technology descriptions
  - Classified and categorized the technology forecasts developed by all teams. Technology areas coming out of the workshop were: a) user interfaces, including interface architecture, I/O devices, graphics and voice; b) resource management; c) control language; d) database systems; e) automatic software development; f) communications; g) simulation; and h) training
  - Integrated the information concerning technology forecasts across teams.
- Workshop Participants: the final half day of the workshop was devoted to a discussion of the technologies identified and described in the brainstorming and forecasting sessions. This discussion was led by the group of team leaders and all participants were encouraged to contribute.

WORKSHOP DATA ANALYSIS AND INTERPRETATION

After the completion of the workshop, the data obtained in each of the three sessions were analyzed. Results of this analysis are presented in RESULTS, pages 42-58. The implications of these results for the workstation design are presented in IMPLICATIONS, pages 59-78.

RESULTS

The information presented in this section represents a synthesis of the technology descriptions and forecasts generated by the various workshop groups. Each technology area is described in terms of its application to the workstation followed by a brief description of the forecasted advances in the technology. The advances are presented in terms of near-term (present through 1992), mid-term (1993-1997), and far-term (beyond 1997). Figure 14 depicts the elements of the workstation as implied by the results of the workshop.

USER INTERFACE

The user interface consists of those elements of the workstation through which the user will directly interact wih the system. For present purposes, the user interface has been partitioned into four areas: interface architecture, I/O devices, voice and graphics. The technology forecasts for each of these areas are described below.

Interface Architecture

Interface architecture refers to the process by which input and output capabilities will be developed for the workstation. In order to achieve the objective of hardware independence for the workstation, the user will have to configure the workstation to accommodate the characteristics of the equipment being used. There are two basic elements to interface architecture: display formatting and dialog design. Display formatting involves the selection and organization of information to be displayed at the workstation. Dialog design is the selection of media and methods (e.g., menus, commands, etc.) by which the user will communicate with the workstation.

The workstation will contain software tools that assist the user in developing display formats and dialogs that are compatible with both the requirements of the experiment and the characteristics of the user's equipment (see AUTOMATIC SOFTWARE DEVELOPMENT, page 52). This software will support development of a "multi-modal adaptive interface" that allows multiple display formats and dialog modes with various hardware configurations. The user will be able to design and prototype any number of display formats and dialog modes, simulate an experiment, and then select the formats and modes that are most effective. In addition, software resident in the workstation will allow the user to modify display formats on-line without disrupting ongoing workstation operations. In order to support the multi-task environment anticipated for the workstation, the software will be capable of generating multiple-window display formats. The software will include a method for validating display formats to encourage conformance with NASA guidelines and established principles of information presentation.

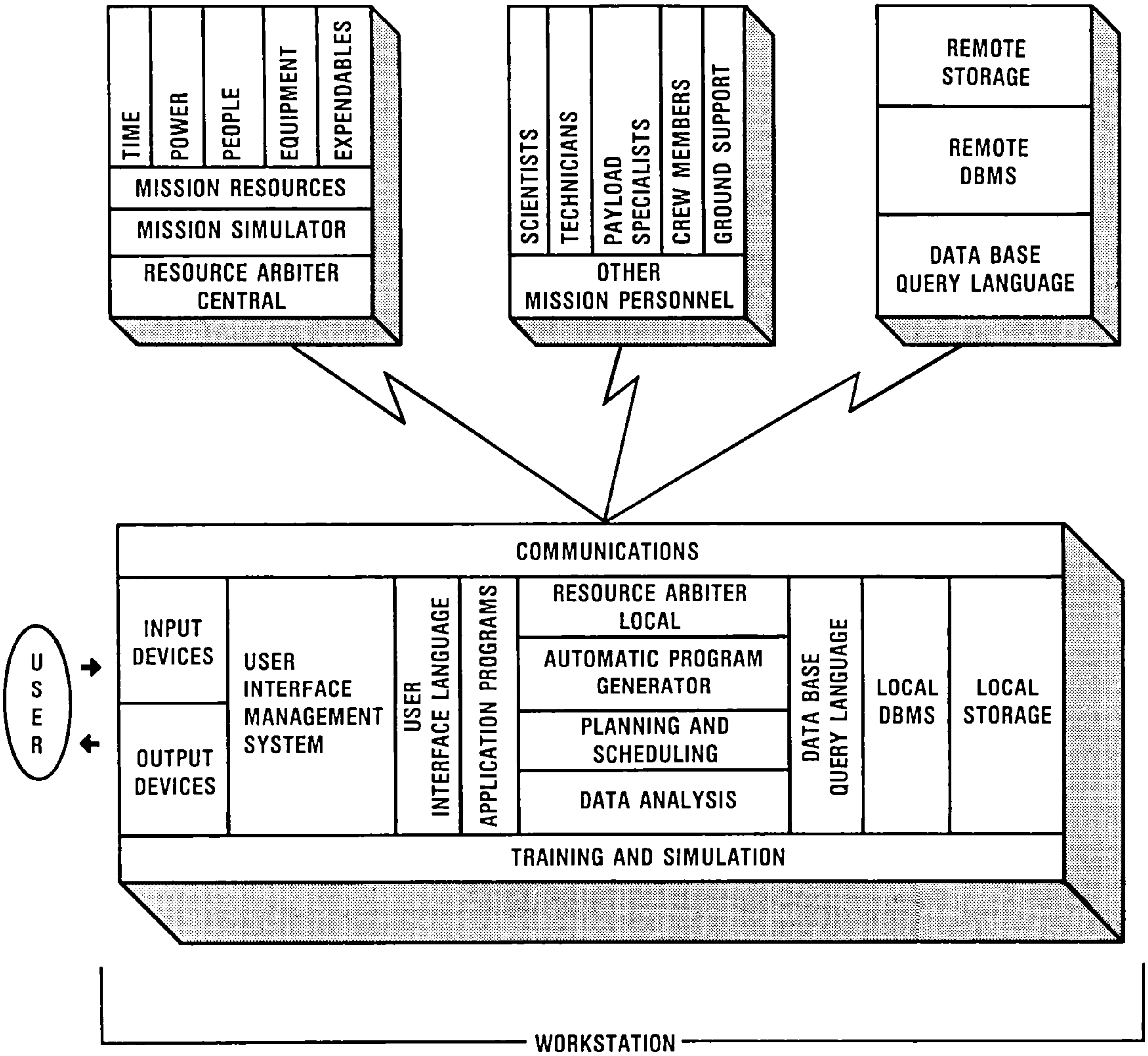

Figure 14. Workstation Elements

In the near-term, it is predicted that software will be available that supports display and dialog formatting for most conventional I/O devices. A NASA guidelines document for display and dialog formatting will be available by 1988. In the mid-term, the software will have sufficient intelligence to model user requirements and suggest display and dialog formats. In the long-term, the software will function as an expert system capable of developing well human-engineered display formats from a high-level description of user objectives.

Dialog development will be directed by a User Interface Management System (UIMS) that serves as a "presentation manager" by supporting the information processing, computational and analytical needs of the user. Figure 15 depicts the relationships between the various elements of the UIMS. The UIMS will employ a common command language (see CONTROL LANGUAGE, page 49) that will functionally separate the user from the various applications programs. The UIMS will perform a two-way translation of user requests into, and out of, the necessary implementation languages. The UIMS will have access to a variety of dialog generating tools, including an "interface author" that will use automated interview techniques to develop rules and algorithms for conducting the human-computer dialog. The interface author is in essence a software engineering analog to CAD/CAM. This method is expected to be particularly effective for developing dialogs for AI systems.

In the near-term, it is predicted that the UIMS will be capable of applying interview and induction techniques for basic dialog rule generation. This capability will be used during experiment planning and scheduling activities and will be tied to simulation capabilities to exercise prototype display formats (see SIMULATION, page 54). At this early stage, all decisions made by the software will require verification by the user. The command language employed by the UIMS will be independent of the machine/operating system (see CONTROL LANGUAGE, page 49). In the mid-term, the UIMS will evolve into a powerful and reliable interface prototyping tool that will require little, if any, user verification for dialog generation. By 1999, the system will be part of a large AI network responsible for integrating a full range of scientific and technological research.

Currently, research in this area is being conducted by Robert Williges, Rex Hartson and Roger Ehrich at VPI, Nicholas Negroponte at MIT, Tony Wasserman at UCSF, Rob Jacobs at NRL, Roger Schank at Yale, Janet Kolodner at Georgia Tech, John Sibert at George Washington University, Dan Olsen at Brigham Young University, Doug Medine at the University of Illinois, Michael Joost and Edward Fisher at North Carolina State, David Lenorivitz at CTA, Peter Wong at TRW, and Randy Davis at Colorado/LASP.

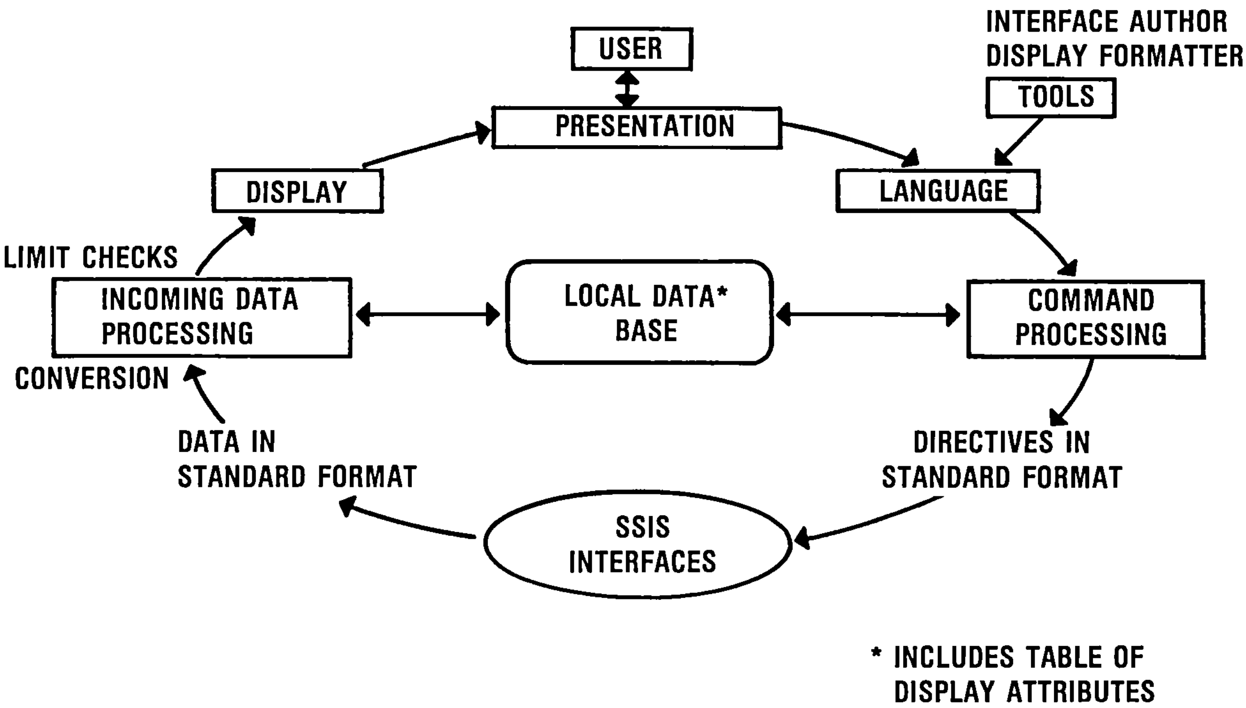

Figure 15. Elemental Relationships in the UIMS

I/O Devices

As previously described, the workstation concept is hardware independent; however, it is anticipated that a standard configuration will evolve that consists of a processor (memory and CPU), a mass storage device, one or more displays, a keyboard, alternate input devices, network interface(s) and a printer. The actual devices selected by the user will depend on the range of projected operational requirements.

In terms of displays, it is predicted that in the near-term, flat panel displays will be available that employ thin-film resistive touch-sensitive screens capable of 99% transmissivity. These displays will be high resolution (1500 x 2000 pixels) and use LCD, parallel axis CRT, plasma or electroluminescent technology. These displays will have full color capability and will serve as both input and output devices. The use of windows and/or multiple screens will become more prevalent as parallel processing capable of supporting multiple, simultaneous applications evolve. Additional input capability will be provided by controllers capable of accommodating three dimensions and up to six degrees of freedom. These controllers should be available by 1995. Jack Hatfield at the NASA Langley Research Center, Marianne Rudisell at Johnson Space Center, Kent Norman and Ben Shneiderman at the University of Maryland, Dave Getty at BBN, Bill Utal at NOSC-Hawaii, and Edward Gueren at Marshall Space Flight Center are active in this area of research.

Graphics

Graphics will be a principal means for presenting information to the user. This capability will extend well beyond traditional data presentation techniques to methods for conducting exploratory and formal data analysis. In addition, digitized video will be used to provide visual access to an experiment and to support teleconferencing functions (see COMMUNICATIONS, page 53). Computer-generated imagery will play an important role in experiment simulation (see SIMULATION, page 54).

In the near-term, software will be available to permit dynamic manipulation of multi-dimensional graphics displays and mixing of dynamic video and graphic images. This capability, coupled with multi-dimensional input devices will allow the user to perform "quick look" assessments of experiment progress by presenting large amounts of data in summary graphic form. With this capability, the user will be able to evaluate the goodness-of-fit of the model and modify the experiment, if necessary. In the mid-term, the trend will be toward 3-dimensional techniques: stereoscopic, varifocal mirrors, and laser-driven displays using helical rotor and holographic procedures. This trend will continue into the far-term with real-time holographic video available by 1999.

The helical rotor technique is being developed by Rudiger Hartwig at the University of Heidelberg under a grant from IBM. Other groups active in the 3-D display area are Battelle Northwest Labs, Stanford, MIT (machine architecture group), Center for Man-Machine Systems Research at Georgia Tech, Polaroid Corporation, Tektronix, Stereographics Corporation, University of California at San Francisco, University of Pennsylvania, MAGI, Abel Associates, and Elographics. In addition, impressive application work is being done in the film industry by such groups as Lucas Films and Digital Productions.

Voice

For the purposes of the workstation, voice input is seen primarily as an ancillary technology; a "third hand" that will serve as a backup to existing and projected input devices during periods of intense manual activity. Voice synthesis is viewed as a practical addition to traditional display technologies for the workstation that will obtain greater prominence as more knowledge of serial display design is acquired.

At present, highly intelligible synthetic and recreated voice is available, capable of generating phonemically-correct connected discourse. Voice recognition will soon be available in a limited capacity capable of accepting connected speech from a constrained vocabulary (<800 words). In order to enhance system reliability, it is anticipated that a fairly rigidly structured interface language will be developed based on a command set that will maximize machine discrimination. In the mid-term, advances in microphone technology will allow greatly enhanced recognition capability. This advance, coupled with a natural language AI system, will produce a machine that is able to interpret (not just recognize) speaker-independent free form speech by 1999. This capability may include an expert system translator to facilitate international research.

Research in this area is being conducted by Doddington and Hollister at Texas Instruments, Markhoul at BBU, Victor Zue and Nicholas Negroponte at MIT, Jim Voorhees and Clay Coler at NASA Ames, Randy Chambers at ARI, Mike Joost at N.C. State, and Carol Simpson of Psycho-Linguistic Research Associates. IBM, NEC, Verbex, Bell Labs, Interstate Electronics Corporation and INTEL are also expected to be active in the manufacturing and application of voice technology.

Resource Management

The space station mission will involve multiple users at separate locations vying for the finite resources of the space station. In the course of discussing this topic at the workshop it became apparent that coordination and integration of near

real-time resource management activities may be a necessary capability of the workstation. This capability is viewed as an "enabling technology" that facilitates, rather than drives, workstation implementation. The types of resources to be managed include:

- time - time available for experiment conduct determined by acquisition or loss of signal, communication bandwidth availability, or other mission event).
- power - electrical power used to control experiment-related equipment, maintain the experiment environment and operate support equipment.
- people - on-orbit and ground-based personnel involved in conducting, monitoring and supporting experiment activities.
- equipment - on-orbit and ground-based equipment (e.g., SAR, LST, etc.).
- materials - expendables required to conduct or support an experiment (oxygen, silicon, etc.).
- facilities - including on-orbit servicing, logistics management, and module arrangement or configuration.

Resource management will have both planning and tracking elements. Initially, the user will develop a plan for conducting the experiment using mission guidelines concerning the availability of selected resources. This plan will address resource expenditure rates across time. The user will develop this plan at the workstation using an automated planning tool to access a central resource management data base (a "resource arbiter") that contains information concerning the type and amount of available resources. The resource arbiter will be capable of resolving conflicts between competing users and between ground station commands and on-orbit capabilities. The tracking element of this capability will compare planned to actual expenditure rates to identify deviations. Such deviations will be reported to the user for reconciliation. As necessary, the user will modify the resource management plan to accommodate changes in experiment requirements. The resource arbiter will have both central and local components. The central component will be responsible for resource management at the Space Station level, whereas the local arbiter will manage the resources that have been allocated to a specific user.

It is predicted that in the near-term software will be available to perform the planning and supervisory element of this function. This software will allow the user to interactively access the resource management system to identify and reserve the type and amount of required resources. As the software evolves in the mid-term, it will have increasingly greater intelligence and power. The software will be capable of learning by expanding its data base of resource management information until, by 1999, the program will be capable of developing a resource management plan for a first-time experiment based on a review and assessment of the resource requirements of previous experiments.

Since the availability and quality of some resources will determine the success of an experiment, the workstation will include an annunciation capability for alerting the user to out-of-tolerance conditions for critical resource parameters. During the planning activity, the user will identify critical parameters and specify nominal, marginal and out-of-tolerance values for each parameter. These will be entered into the resource management system and the necessary monitoring functions will be scheduled and performed. This annunciation capability will interact with the UIMS of the workstation. In the near-term, this function will require considerable human involvement during planning, with the system assuming responsibility for monitoring and alerting functions. Response to out-of-tolerance conditions will be automated for most parameters. In the mid-term, the system will be capable of inferring critical parameters and values from previous experiments and setting up a first draft of the annunciation protocol.

Researchers at NASA Ames, MSFC and JPL, and the Center for Man-Machine Systems at Georgia Tech are expected to be active in this area. MSFC is particularly concerned with Space Station logistics simulation and data base development.

CONTROL LANGUAGE

The science user will have to control and monitor a variety of processes and devices from the workstation. For example, a typical experiment set up will involve accessing several data bases, configuring a communications network, and establishing control/feedback loops for some set of experiment-related equipment. Since one of the objectives of the workstation is to minimize the amount of time the user must spend doing non-experiment-related tasks, the workstation will have a common control language that will allow the user maximum control with minimal effort. This implies a high level language that is goal-directed and functions as a master controller capable of translating the commands of the user into a series of parallel activities.

It is predicted that in the short-term, a general user interface language (UIL) will be developed based on a set of standard commands that will allow the user to control experiment processes and equipment using slightly constrained English. In the mid-term, this language will evolve into a context-oriented command language that is capable of extracting meaning from the operational environment by inferring the meaning of a command from preceding events and requests. For example, the user may simply instruct the machine to "increase sampling rate" and the machine would infer the parameter being sampled as well as the actions required to effect the increase. Obviously, the dialog will include feedback to the user regarding machine inferences and will allow the user to override and correct false assumptions.

At this stage the language will be capable of generating code and/or selecting previously developed algorithms, as appropriate, to implement user requests. (See Section 3.5, Automatic Software Development). In the long term, the UIL will become concept oriented, capable of accepting a problem or set of related problems and performing the functions (e.g., generating the command strings) necessary to achieve a solution. Again, the user will be continually apprised of the machine's actions.

It is expected that Larry Peterson at the Army's Human Engineering Laboratory and Phil Andrews at the Naval Sea Systems Command (DOD STARS program), Karen Moe at GSFC, Al Wetterstroem at JSC, and Larry Morgan at KSC will be involved in the development of this technology. A NASA team representing JSC, KSC and GSFC is currently developing a specification for a standard user interface language for the Space Station.

A related prediction involves the use of icons as a method for implementing a command language. Icons are images that depict machine functions in a pictorial fashion and have associated semantic and syntactic rules that allow them to represent language elements. The use of icons will minimize the need for memorizing machine-specific commands.

In the short-term, it is predicted that a complete set of standard icons will be available that will minimize the requirement for entering verbal instructions at the workstation. In some cases, these icons will involve animation to depict the progression of events under control. In the mid-term, the user will be able to link icons to form command strings. These icons will have some intelligence and will be capable of recognizing misuse by the user. In the long-term, the workstation will have the capability to develop and store specialized icons that handle specific functions. The workstation will include the necessary rules to ensure that such icons are compatible with the command language.

The research required to achieve this forecast is currently being conducted by Kent Norman at the University of Maryland.

DATA BASE SYSTEMS

The science user will have to work with a variety of data bases in order to access, retrieve, manipulate and store the large volume of data expected to be used during the planning, conduct and analysis of an experiment. These data bases will vary in size, structure and complexity ranging from the relatively small experiment-dedicated data base located at the workstation to the large, centrally located resource management data base (see Resource Management, page 47). Therefore, the Data Base Management System (DBMS) for the Space Station Data System may employ distributed processing that will be an extension of current local area network technology. During the workshop, two DBMS technology areas were identified as critical to workstation design: data base language and data management and storage.

Data Base Language

In order to minimize user training requirements, the workstation will employ a standardized or common data base query language (e.g., SQL) that is independent of the specific hardware/software of the data base being used. This concept is similar to that proposed for the common control language (see CONTROL LANGUAGE, page 49). The query language will utilize a layered approach to allow machine/software independence and portability. A major element of this language will be a filtering capability that will handle "unstructured" data using pattern-recognition technology. In this context, unstructured refers to the lack of a single, standardized data format for the various data bases.

In the near-term, the workstation data base query language will be an extension of existing data base languages and utilities. At present, the greatest barrier to advancing this technology is the development of new concepts and techniques for expressing and recognizing data patterns. These advances are predicted to occur in the mid- to far-term. By 1999, it is predicted that dedicated pattern recognition hardware and software will be available in prototype.

Research in this area is currently being conducted by Mark Weiser at the University of Maryland, Barry Jacobs at GSFC, Al Aho at Bell Labs, and Craig Thompson at Texas Instruments.

Data Management and Storage

Since much of the time the user will spend at the workstation will involve locating, accessing, manipulating and storing information, the efficiency of the data management and storage system will determine, to a large extent, the utility of the workstation. One of the objectives of any DBMS is to provide a dynamic model of the stored data that accurately reflects the user's perspective. As it applies to the workstation, this objective will be met by embedding some level of intelligence in the DBMS that will work in concert with the UIMS to structure and organize the presentation of data to the user according to how the data are to be used.

In order to support multiple users in simultaneously accessing the various data bases, the workstation will have to contain multiple, dynamic (multiplexed) access paths.

In the near-term, it is predicted that a standard or common data base query language will be available that will allow the user to access any DBMS in the Space Station network. The use of more sophisticated search strategies will permit a break in the link between the query language and data organization. Read/write optical storage media will be available in the near-term that will have a capacity of 100 MB. In the mid-term, it is predicted that the trend will be toward machines with specialized data base architecture. Optical storage disks will replace magnetic storage media

in the mid-term. These devices will have multiple read/write heads that use beam splitting to allow multiple spot reading and writing of disks. This capability will greatly increase the speed with which data can be stored and retrieved. In the far-term, data bases will merge with AI knowledge bases to produce a new generation of data base management systems. The standard optical storage device will be capable of a 1 GB capacity.

Persons predicted to be active in this area of research are Matthew Koll at George Mason University, Dave Morris at GE, and Barry Jacobs at GSFC. TRW, Phillips, Sony, 3-M, IBM, Hitachi, Optotech, Matsushita, ISI and Cherokee are also expected to be involved in the development of this technology.

AUTOMATIC SOFTWARE DEVELOPMENT

In order to support the wide diversity of user applications expected for the workstation, some level of automatic code generation capability will be required. This capability will be particularly important for supporting casual users and users with uncommon requirements. Automatic programming will be integral to a variety of workstation applications, including development of the user interface (see Interface Architecture, page 42), configuring communications networks (see COMMUNICATIONS, page 53), and generating special purpose data management and analysis tools (see DATA BASE SYSTEMS, page 50).

Currently, individual programming environments have internally compatible development tools capable of performing a variety of functions. What is required for the workstation is the ability to access and combine selected tools from different programming environments. It is envisioned that the workstation will contain a general purpose translator (GPT) that can assemble and integrate a number of independent and otherwise incompatible tools from a variety of commercially available environments. The GPT will be independent of the specific hardware and operating system on which it is implemented. Initially, the GPT will be developed in either the C or ADA language. The GPT's capability will extend to development of algorithms for multiple-instruction/multiple-data processors and compilers for translating single-processor code into multiple-processor/multiple-task code.

A major element of this technology will be the ability to develop, stockpile and catalog individual software modules. These modules will vary in content and application from relatively simple data manipulation algorithms to complex expert system knowledge bases that include all of the facts, inferences and procedures for a particular area of expertise. These modules will be available for retrieval and assembly into unique applications programs that support individual user requirements. For example, a user may want to assemble an application program to assist in mapping instrument output into and out of the telemetry data stream. This program might

consist of a telemetry system expert module and some set of algorithms for managing (e.g., collecting, tagging, and compressing) instrument output. If a module is not available "off-the-shelf," the system will automatically generate the necessary code and catalog the new module for future reference. The human-computer dialog for this capability will involve an interactive query format to develop a program attribute specification that the system will translate into a functioning program.

In the near-term, it is predicted that the software will be available to allow the user to interactively define program specifications at the workstation. Actual program construction will be semi-automated, with the machine selecting off-the-shelf modules and then presenting their capabilities to the user for review and acceptance/rejection. Program capabilities not available off-the-shelf will be developed off-line by human programmers, using semi-automated program generating techniques. In the mid-term, the system will be capable of some automatic code generation. The GPT library of software modules will have grown substantially, particularly in the area of expert knowledge banks. The system will be capable of constructing an application-specific expert system by combining various expert modules. In the far-term, the system will be fully capable of automatically specifying, designing and prototyping virtually any application program based on a high level description of user requirements. At this point, the system will be capable of assembling and integrating tools across computer systems and performing remote procedure calls.

Currently, research in this area is being conducted by Mark Weiser at the University of Maryland, Kennedy at Rice University, Kuck at the University of Illinois, Chris Herot at Dragon Corporation, and Phil Andrews and Larry Peterson within the DoD STARS Program. Additional research is expected from Stanford, SRI, Carnegie Mellon, MIT, Teknowledge, Xerox PARC, and the Computer Corporation of America.

COMMUNICATIONS

The workstation will function as a terminal in a widely distributed, high-speed voice, video and data communications network. The workstation will provide the user with access to other science users, a variety of data bases, and on-orbit equipment and personnel. One of the major advances in technology projected for the workstation is the use of video teleconferencing as a standard communications medium. It is expected that video teleconferencing will significantly improve the quality of communications between the workstation user and the on-board crew and payload specialists.

In the near-term, it is predicted that local area networks (LANs) will employ fiber optics technology capable of transmitting from 200 to 1000 megabits per second, and that satellite links will be capable of transmitting at a 100 MB

rate. Due to the expected high traffic density of the ground-to-space/space-to-ground link, some bandwidth compression will be required, particularly for video images. It is expected that this compression will involve the elimination of non-critical bits on the transmission end, and image restoration through frame comparison and pixel averaging on the receiving end. In the mid-term, the network operating system will include intelligent gateways that automatically perform the "hand shake" protocols between the various elements of the network. In the far-term, the use of networks will become increasingly transparent to the user, allowing transmission and reception to be conducted with minimal user involvement.

Research in this area will be performed by Thomas Sheridan at MIT, Sid Smith at MITRE, Ira Sax at IBM, and Gerald Chaiken at Redstone Arsenal. Tony Villasenor at NASA Headquarters, Lorenzo Aguilar of SRI, International, and John Arslanian at GSFC/543 are active in video teleconferencing research. Other organizations expected to be active in this area are Sperry Flight Data Systems; Bridge, Inc., Communications and Tracking Division at JSC; the National Bureau of Standards; and Bell Labs.

SIMULATION

This section describes the use of simulation for non-training applications. Training applications are addressed in TRAINING, page 56.

The primary non-training application of simulation for the workstation will be as a fast-time predictor system for resource management, experiment checkout and control, and interface prototyping. Although the Space Station is expected to maintain an average altitude of only 215 nautical miles, the communications link, which will involve ground lines, a central communications facility and up to two geosynchronous satellites, will necessitate a 2-6 second delay, depending on the location of the user in the network. As a result, instantaneous control of experiment equipment and resources will be impossible from ground-based workstations. What is required is access through the workstation to a fast-time experiment simulator that will predict and display the effects of proposed user actions on experiment equipment and resources in something approaching real-time.

As discussed under Resource Management, page 47, resource management will be a critical function for ensuring the success of the various Space Station experiments. In order for the user to anticipate potential resource problems, the workstation must have simulation capability for predicting the rate of resource expenditure for alternate experiment scenarios. For example if a user encounters a problem while conducting an experiment that requires dedicated access to the synthetic aperture radar (SAR), the workstation simulation capability could assistthe user in re-scheduling access to SAR by

simulating the instrument and its host environment (e.g., platform) resources, and identifying an available and acceptable time frame.

With regard to experiment checkout, the workstation will provide capability to simulate the operation of experiment equipment to ensure compatibility of different Space Station and payload equipment, and the usability of experiment data. This capability will allow the user to test and evaluate the experiment's design prior to actual experiment conduct. If any problems are identified, the user will be able to modify the design and repeat the simulation, as necessary, until the desired results are obtained. In addition to checking out the experiment prior to conduct, the simulation capability will allow the user to perform "quick look" projections as the data are being collected to determine how well the experiment is proceeding.

A simulation capability will also assist in the diagnosis of problems and the isolation of failures. Simulations can be generated based on the set of symptoms, and probability distribution for alternate causes can be developed.

The major concern for equipment control involves presentation of control feedback for continuous control tasks such as pointing a free-flying telescope or controlling a manipulator arm. Simply stated, the problem is one of timing. Without direct and immediate feedback of control effect, the user must estimate the amount (i.e., extent and duration) of control input necessary to achieve the desired response. Since the equipment response will be completed before the effect can be displayed to the user, the problem becomes one of assisting the user in anticipating the effect of a control action by displaying a fast-time analog of the equipment's predicted response. Obviously, the complexity of the problem increases as the number of degrees of freedom of the controlled equipment increases. The worst-case example of this problem might be a ground-based user attempting to control a free-flying remote manipulator with six degrees of freedom. In this case, a 2-6 second delay would greatly increase the user's workload.

There are at least three general solutions to this problem, all of which have implications for workstation design. The most effective solution is to provide the user with supervisory control capability for all experiment equipment. In this case the user would simply issue a goal-directed command to the system and the system would execute the necessary actions to achieve the goal. The drawback to this solution is developing the command language and associated software that anticipates all possible user requirements for all experiment equipment. The second solution involves allocating control of all on-orbit equipment that requires continuous control to the on-board payload specialists. This solution depends on availability of on-board payload specialists' time to interact with the user to provide support for experiment control. The third solution involves providing the user with

predictive displays which present the effect of a control action before the command is executed. In this case, only equipment responses must be modelled. This solution was judged most viable by the workshop participants.

With regard to interface prototyping, the workstation will be capable of simulating the conduct of the experiment using alternate interface configurations. These configurations may involve different I/O devices, different display and dialog formats, different information presentation techniques, different command and control strategies, etc. This capability will allow the user to select the interface configuration that is most effective for the planned experiment. Once developed, this capability will reside in the workstation to allow the user to examine alternate interface configurations without interrupting ongoing experiment operations.

Although it is expected that advances in programming for modelling/simulation will facilitate implementation of this capability, no major breakthroughs in technology are required.

Persons currently active in this area of research are Rusty King at the University of Florida; Newell at Carnegie Mellon; Morgan, Card and Brown at Xerox; Chris Mitchell and T. Govindaraj at Georgia Tech; and, Thomas Sheridan at MIT. Other organizations expected to be involved in the development of this technology are IMSEI; N.C. State; and NASA.

TRAINING

The workstation concept poses unique training requirements in that expected users will span a wide range of backgrounds in terms of experience and expertise. Although all users will be experts in their respective scientific disciplines, many will be unfamiliar with the details of the Space Station program and, at least initially, in the operation of the workstation. The solution to this problem is seen as consisting of an amalgam of decision aiding, job performance aiding, simulation and user modelling techniques that will allow the workstation to automatically develop an embedded training program that is tailored to the needs of an individual user.

A central element in the workstation training concept is the capability to create a model or profile of the workstation user. This capability will consist of a catalog of user characteristics, indexed by application area and user expertise, that will allow the workstation to anticipate a user's training requirements. By monitoring the user's interaction with the workstation, a model of the user will be developed that accounts for the various conceptions and misconceptions the user may have about operating the workstation. For example, a first-time user attempting to configure a communications network will have different conceptions about workstation operation, and hence different training requirements, than an experienced user performing the same function. By drawing on its catalog of user models, the workstation will make assumptions about

the present user's level of expertise and will offer advice, direction and training accordingly. As the model of the user evolves, the workstation will develop an embedded training program that accommodates the specific requirements of the user. The system will automatically modify its model of the user to reflect improvements in the user's understanding of workstation operations. The workstation will also track the user's performance capability over time and will be capable of determining that refresher training is needed to enhance perishable skills.

The training program will consist of experiment simulation capability, on-line help and assorted decision aids, as necessary, to support the user. In terms of simulation capability, the training program will employ the same models used for resource management and experiment control (see SIMULATION, page 54). This capability will allow the user to learn the operation of the workstation by conducting "what if" simulations for the various phases of experiment design, conduct and analysis. This capability is expected to be particularly valuable for familiarizing on-board payload specialists with the specific requirements and constraints of the various experiments. In the course of conducting these simulations, the system will identify user misconceptions and propose training exercises to correct them. These exercises will use decision-aiding techniques that will subsequently become part of the on-line help program. Individual decision aids will be cataloged and stored as modules in a central repository for recall and use by other users.

The on-line help program will provide multi-media (i.e., text, voice, video and graphics), context-oriented assistance to the user. Context-oriented means that the program will automatically display help routines and decision aids applicable to the task being performed by the user when a misconception is detected. All help routines will be manually accessible to the user, as needed. Use of the on-line help program will be "non-destructive" in that the user will be able to access the help function without interrupting the ongoing operation of the workstation. This will be accomplished through a multiple window technique (see Interface Architecture, page 42). In addition to traditional forms of on-line help (e.g., functional descriptions and procedures), the projected system will contain diagnostic and corrective procedures to assist the user in detecting and recovering from errors. For example, if the data sampling rate selected by the user exceeded the transmission rate for the telemetry system, the help program would alert the user to the error and simulate the effect on data quality. The program would then assist the user in recovering from the error.

In the near-term, it is predicted that catalogs of user misconceptions and multi-media, context-oriented help routines will be available for one or two applications. These, along with expected simulation models, will permit implementation

of a rudimentary embedded training program. In the mid-term, this capability will be enhanced through expanded catalogs of user misconceptions and improved on-line help routines. In the far-term, requirements for embedded training are expected to diminish as the system becomes more automated.

Persons currently active in research related to this technology forecast are Eliot Soloway at Yale; Don Norman at UC - San Diego; Mark Weiser and Ben Shneiderman at the University of Maryland; John Black at Columbia; Deborah Boehm-Davis at George Mason University; and Christine Mitchell at Georgia Tech.

IMPLICATIONS

This section describes the implications of the results of the workshop as they apply to four broad areas: technology thrusts, the roles of the workstation, special issues, and the ongoing workstation program.

TECHNOLOGY THRUSTS

This section describes the implications of the results of the workshop as they apply to ongoing research to support the design of user workstations. This section is organized around the concept of technology thrusts. A technology thrust is an area of research for which a clear and immediate application to the workstation was identified during the workshop. The objective of this section is to translate the results of the workshop into a research and development program for user workstations that accurately reflects anticipated trends in technology.

User Interface

The projected trends in user interface technology for the workstation imply the following technology thrusts:

- Multi-Modal Adaptive Interface
  This concept involves the development of a dynamic, interactive, intelligent interface and related display prototyping tools that will allow the user to design and implement self-tailored display formats and dialog modes for use with various hardware configurations. This capability will assist users in developing the optimal interface for their requirements. The success of this concept rests largely on significant advances in software engineering, particularly, automatic program generation and artificial intelligence. Although current research activities, such as the DOD STARS (Software Technology for Adaptable, Reliable Systems) program and the NASA User Interface Language and TAE (Transportable Applications Executive) projects should provide a sound foundation from which to build this capability, additional research is required in several areas, including: 1) development of applicable design guidelines for advanced display and dialog formats; 2) identification of common user functions; 3) specification of the characteristics of a standard user interface language; and 4) methods for modelling devices in order to develop a "virtual device interface" that will allow the workstation to be connected to a variety of peripheral devices.
- User Interface Management Systems (UIMS)
  The UIMS is the technological corollary to the multi-modal adaptive interface. The UIMS will provide a functional

separation between the interactive dialog and the application program by presenting an abstraction of the user interface to the application program and an abstraction of the application program to the user. This will allow the user to customize the interface without impacting the design or operation of the various applications programs. The UIMS will have access to a variety of tools and techniques, such as an "interface author" and algorithm-generating interview protocols, for assisting the user in designing the interface. Additional research required in this area includes: 1) increased processing speed in order to minimize delays resulting from the additional protocol layers required to obtain machine/application independence (this issue will be particularly critical for those applications requiring real-time or near real-time operations); 2) selection of the most effective dialog mode for the interface author (e.g., functional decomposition vs. iterative prototyping); and 3) development of rules and heuristics for governing the display of information to the user.

- Multi-task Display Windows
  This concept involves partitioning the display area into multiple, discrete "windows" in which the user may display selected information for performing simultaneous tasks. The hardware/software technology necessary to support this concept are presently available (e.g., Macintosh by Apple, Top View by IBM); however, additional human performance research is required to optimize this interface. This research should focus on: 1) methods to optimize human information throughput rates to avoid overloading the user; 2) the use of color and other coding techniques to facilitate search and recognition in a multi-window environment; 3) methods to standardize the display of critical information in a multi-window environment; 4) development of control devices that are compatible with the multi-window environment; and 5) methods for partitioning and securing memory to ensure that the various window activities do not interfere with one another.
- Input and Output Devices
  Although the use of advanced technology, such as holographic displays, may be attractive, the results of the workshop indicate that current I/O devices are adequate for achieving the Space Station mission. However, in order to optimize the use of the various I/O devices, additional research is warranted in the area of device selection. Heuristics and guidelines for selecting the optimal I/O device for a specific application that are based on empirical research on human performance need to be developed. This issue will be particularly important for controllers with more than three degrees of freedom and high-resolution displays. High resolution displays will become an increasingly critical element of the workstation as advanced graphics and video technologies become integral to the various workstation applications (e.g., data analysis and teleconferencing).

- Graphics
This area of technology is relatively mature in terms of capability. However, it was the consensus of the workshop participants that significant advances can be made in the application of existing graphics tools and techniques. Current trends in development indicate that dedicated "graphic engines" will be available that will greatly increase the speed and capability of graphics applications. Given the availability of the necessary software and hardware, the issue remains as to when and how to use graphics to improve the human-computer dialog, particularly in the areas of data presentation and analysis. Research is required that addresses innovative approaches to the use of graphics in the telescience environment.
- Voice
As with graphics, the issue with voice technology is not whether it will be available, but when and how it should be applied. This requires empirical research to determine the advantages and disadvantages of voice technology relative to more traditional I/O devices for specific applications. If voice technology emerges as a superior dialog method, the question remains as to when and how it should be applied to the workstation. Once the applications have been identified, additional research will be required to 1) select commands that are maximally discriminable for machine recognition; 2) develop dialog protocols that effectively utilize voice I/O; and 3) identify methods for ensuring the security of voice-based control and feedback loops.
Related research thrusts: Control Language (page 62); Automatic Software Development (page 64); Simulation (page 65).

Resource Management

Resource management will be a critical function for the workstation user. The user will have to both plan and track experiment resources throughout the experiment process. Given this requirement, the following technology thrusts are indicated:

- Resource Arbiter
The resource arbiter is more of a composite of functions than a literal technology. The resource arbiter will be a "black box" that resides somewhere between the various workstation users and the resources of the Space Station system and is responsible for 1) reviewing requests for resources; 2) resolving conflicts concerning resource allocation; 3) allocating resources to the various users; 4) monitoring resource expenditure; 5) alerting the user to off-normal resource conditions; 6) resolving resource availability problems through rescheduling, on-orbit servicing, or reallocation of resources; and 7) updating resource status logs. The research required to implement the resource arbiter involves developing the algorithms

necessary to predict, monitor and control the rate of expenditure of Space Station resources. Significant issues include:

- How to translate a high level description of experiment requirements into a detailed inventory of experiment resources
- How to resolve conflicts for resources (i.e., how to prioritize users/experiments)
- How to identify and monitor critical resource parameters
- When and how to alert users to off-normal resource status
- How to ensure the integrity and timeliness of the resource data base
- How to allocate control authority for on-orbit servicing to ground vs in-flight control
- The relative roles of humans vs machines in resource management.

Related technology thrusts: Simulation (page 65) and Data Base Systems (page 63).

Control Language

The predicted trends in language are toward a high-level, standardized, goal-directed user interface language (UIL) that allows the user to control an experiment using slightly constrained English. Technology thrusts related to this forecast include:

- Standard Vocabulary
  In order to develop and implement a standardized UIL, a complete list of the most common terms and phrases used for 1) equipment nomenclature, 2) command and control, 3) communications, 4) data management, and 5) system personnel, will have to be developed. From this list, a standard vocabulary can be developed that has the broadest possible application. Although standard vocabularies exist for a variety of applications, significant research issues remain. For example, should a term be selected for inclusion in the vocabulary based on 1) its current familiarity to the user population, in order to maximize positive transfer of training; 2) according to its phonemic qualities in order to maximize machine discriminability to facilitate future voice recognition applications; 3) according to the ease with which it may be translated into graphic form for use with icons; or 4) some weighted combination of all three?
- Icons
  The use of icons to minimize requirements for verbal input/output at the workstation could facilitate the development of a standard UIL. Significant research issues include:
  - Are icons significantly better (e.g., faster, more reliable, easier to learn, etc.) than traditional dialog forms?

- What is an acceptable criterion for "recognizability" for an icon and how do you select an icon to ensure that the criterion is met?
- What is the maximum number of icons that can be recognized by a user without referring to a lexicon?
- How should icons be animated to depict progression of events and processes?
- Can icons be linked to form command strings?

Related technology thrust: Automatic Software Development (page 64).

Data Base Systems

- <u>Data Base Language</u>
  One of the principal issues in data base systems for the workstation is how to facilitate data access by the user. One solution is to develop a standard query language that would allow the user to access all available data bases using the same command set. Given that such an approach is feasible, research will be required to develop a standard command set that will accommodate all possible user data base functions. An alternative to a standard query language is a query language translator that could reside in the UIMS. This translator would be capable of converting high-level user commands into a query language appropriate for the data base in use.
- <u>Data Management and Storage</u>
  It is a generally accepted axiom of data base management systems that data should be recorded only once and then shared by the various users of the system. This assumes that the data can be structured and organized in a manner that accommodates the requirements of all users. The problem with large, distributed data bases, such as those proposed for the SSIS, is that it is difficult to organize and enforce the control of format. In order to overcome this problem, research is required into how to improve data base search strategies to identify and manipulate incorrectly formatted data.
  Since some user queries may require integration of data from several sources, a method needs to be developed for simultaneously accessing multiple, remote data bases. Given that simultaneous access is possible, the question remains as to where and how the processing should be done. Is a central facility that handles all processing requests and transmits the results more efficient than a network of local processing facilities? What are the implications for processor size and speed, and communications bandwidth for these two options? Where will the different data products of science data be stored, and who will have access to them?
  Research for storage media should be directed at developing the technology to allow write/read/erase of optical disks.

Related technology thrusts: Communications (page 65) and Automatic Software Development (below).

Automatic Software Development

Automatic software development is not a new concept. Compilers that translate a programmer's specification for an algorithm from a higher level language into a computer's primitive code are examples of automatic programming. The automatic programming capability envisioned for the workstation will allow the user to develop unique, self-tailored applications programs. In order to accomplish this, research is required in the following areas:

- Inferential Reasoning
  Computers are infamous for their inability to "fill in the gaps." In order for the automatic programming function to effectively serve the user, it must be capable of working from a partial or fragmentary description of the desired program. This implies the ability to draw inferences. Research is needed that will specify the universe of request that may be expected from a workstation user. These requests must then be systematically decomposed to provide the computer with a semantic infrastructure from which to draw inferences concerning the intent of the user.
- Flexible Transformations
  Since the program specification provided by the user will be a natural language, object-based description of what is to be done, (i.e., the user will instruct the computer to "Build me a program that does X"), the automatic programming function may have to perform multiple transformations of the program description before achieving the desired end. Research is required to develop a knowledge base with the appropriate transformation rules that can be used to convert the high-level program description into lower-level descriptions, and eventually into the target language. Such rules should be bi-directional, allowing the program to convert the target language back into natural language for output.
- Optimization
  The automatic programming function should be capable of optimizing a program for efficiency. The automatic programming function must be capable of recognizing and discarding unreasonable implementations in order to arrive at a relatively efficient program. Similarly, the automatic programming function must be capable of anticipating and controlling effects of local optimizations on global optimizations. Research is required to develop the necessary rules to accommodate this requirement for the combination of equipment and languages expected for the SSIS.
  Related technology thrusts: User Interface (page 59), Control Language (page 62), and Data Base Systems (page 63)

Communications

One of the major issues for workstation communications is the development of intelligent gateways that automatically perform the "hand shake" protocols between the various elements of the network. Research is required to develop a virtual device interface to assist in making these connections. Current implementations of this concept often have excessive processing "overhead" that severely undermines utility. Other research areas include development of 1) standard message formats; 2) methods to compress video images without losing image quality; 3) techniques to restrict access to network elements to ensure security and privacy; and 4) guidelines for applying video teleconferencing techniques.

Related technology thrust: User Interface (page 59)

Simulation

The principal non-training applications of simulation will be in the areas of experiment definition and planning, resource management, experiment checkout and experiment control, and interface prototyping (see page 54).

As with any simulator, the major questions involve 1) what aspects of the system to simulate; 2) to what fidelity; 3) how to develop the model of the experiment for simulation; 4) how to select measures of performance effectiveness and utility; and 5) how to present the simulation to the user. The workstation system will be responsible for managing the expenditure of critical resources allocated to the experiment. Since it may reasonably be expected that some experiments will be modified as they are being conducted, the user must be able to simulate the effects of alternate paradigms on allocation of resources and the rate of resource expenditure. This will allow the user to select the paradigm that both meets the objectives of the experiment and affords the most effective and efficient utilization of experiment resources. If no effective paradigm can be developed within the constraints of the available resources, the problems will be referred to the central resource arbiter for resolution (see RESOURCE MANAGEMENT, page 47).

Research is required to develop workstation tools that will assist the user in designing an accurate model of the experiment for simulation. These tools should be well integrated with the automatic planning tools used by the resource management system. These tools will provide an interactive process whereby the user is systematically queried to identify critical aspects of the experiment to be simulated. These "critical aspects" will be those that the user needs to make decisions concerning the current status and probable outcome of the experiment. These critical aspects will provide initial indication of the parameters to be monitored by the experiment status annunciator system. In addition, the user will specify the level of simulation fidelity (i.e., error tolerance) required and the

most appropriate method for presenting the simulation. During this exchange, the system will also query the user regarding information required for mission simulation.

A similar process will be required for experiment checkout and control, and interface prototyping.

Related technology thrusts: Resource Management (page 61), Data Base Systems (page 63), Automatic Software Development (page 64), and Training (below).

Training

One of the major advances envisioned for the workstation is the use of a computer-generated model or profile of the user to automatically develop embedded training and online help programs that are tailored to specific needs of the user. When the user logs onto the system for the first time, the system would develop a user profile by requesting specific demographic information, such as user class (e.g., science, technical, crew, or payload specialist), specialty area (e.g., astronomy, chemistry, mechanical servicing, etc.), previous experience with the workstation, and present workstation application (e.g., experiment definition). Based on the user's responses, the workstation would select the generic user model that best fits the user's characteristics from the system's library of user models. The workstation would use this model to determine the type and amount of embedded training/online help to initially provide the user. This model would then be saved under the user's ID/password, and called up each time the user logs onto the system. The system would continuously revise and update the model as the user's requirements and skill levels change. In order to implement this capability, a significant research effort may be required to obtain sufficient data to develop a series of workstation user models and a catalog of "user misconceptions" from which to infer the training/help requirements of the various users. This may require access to training records for a large number of workstation users or users of comparable systems.

The initial training received by the user might consist of a "guided tour" of the workstation's functions and capabilities. This training would provide the user with sufficient understanding of workstation operation to begin productive work. At any time during a transaction, the user could request, or the workstation might perceive the need for, additional training. When this occurs, the training presented would be consistent with the current model of the user.

User-initiated online help programs are relatively simple to develop and are fairly common in today's systems. Machine-initiated online help/training, on the other hand, poses significant research (and philosophical) questions. For example, could such a system be capable of accommodating individual differences in problem-solving strategies, or would all users have to employ the same strategy? Consider the

question of what constitutes an error. Is an error any action performed by the user that is inconsistent with the system's model of flawless operation, or must the action have a demonstrable and degrading impact on system performance? How would the system handle temporal errors, particularly errors involving delayed response by the user. (It would certainly be untoward for the system to "stand by" and allow the user to make an error of timing. By the same token, it would be extremely frustrating for the user to be continually harangued by the computer to "hurry up, you're running out of time!"). This raises a final question concerning the role of humans in advanced systems. If the system is indeed capable of detecting errors, then it must "know" what the correct response should be. The question then becomes, why do we need a human operator at all?

Related technology thrusts: User Interface (page 59), Simulation (page 65).

Workstation System Technology

The preceding subsections of this report have discussed workstation technology advancements at an elemental level. Technology development will also be required to support and sustain the interface between the remote experimenter and the Space Station experiment.

One technology thrust discussed at the workshop was the need to enable workstation growth and expansion as new technologies are developed. It was suggested that the workstation system would never be a static collection of capabilities but rather would be continually changing to keep pace with the advancements in workstation technologies. Such an ongoing improvement process must be addressed at the overall system level, since changes to one technology element will usually impact other elements. The technology thrust here is essentially to support modular, evolutionary development, from concept to prototype throughout the lifetime of the system.

Another important system level technology thrust identified at the workshop was the need for system test and evaluation to establish the cost-effectiveness of system operation and to identify and correct workstation problems. Techniques for embedded testing were discussed which included not only hardware and software tests but also evaluations of human performance capability.

A final workstation system level technology thrust which surfaced at the workshop was the need to establish the role of the human in the operation and management of the system. This issue was most pronounced in areas involving the application of artificial intelligence, where conventional wisdom regarding the utilization of human capabilities seemed least appropriate. Traditional assessments of the relative capabilities of humans and machines have emphasized the distinctions between the two. Humans have been noted for superiority in areas such as pattern

recognition, adaptive responding, inferential and inductive reasoning, and creative problem solving. Whereas machines were touted for such abilities as sensing stimuli outside human ranges, deductive reasoning, indefatigable monitoring for anticipated but infrequent events, rapid and reliable processing of coded information, and repetitive operations. It became obvious during the workshop that these assessments are quickly approaching obsolescence. The question facing today's designers is how to capitalize on the capabilities of current and predicted machines while maintaining a challenging and meaningful role for the human. The answer to this question may require us to redefine the traditional roles of the human in systems.

As machines become competent in domains historically reserved for humans, the human role will become increasingly supervisory in nature. This trend is already evident in many advanced processing control industries where humans spend more time monitoring and directing machines than operating them. How these trends will affect the role of the science user is unknown. Therefore in addition to those issues generally addressed regarding the allocation of functions to humans and machines, the following questions should be considered:

- Which functions, irrespective of their prospects for automation, contain the intrinsic motivators for the scientific endeavor?
- How can the workstation support the user in performing these functions without engendering a sense of diminished control on the part of the user?

ROLES OF THE WORKSTATION

This section identifies workstation roles that are implied by the results of the workshop. The issues of standardization, translation, representative models, expert systems, information repository, and hardware technology are examined in light of assumptions made in Results, pages 42-58.

The Workstation As A Standard View Into SSIS

The workstation, as a tool for the user, must provide a uniform window into the widely distributed Space Station Information System. The workstation should also be modular and configurable to the particular needs of the user. Reconciling these two requirements depends upon the establishment of standards which ensure that a particular workstation configuration can interface to the Space Station system as a whole. To this end, standards must be established for both hardware and software elements of the workstation.

At the hardware level, standards for a virtual device interface would allow different devices to be attached to the workstation without the need for reprogramming. This will become increasingly important as the pace of technology continues in obsolescing last year's model through the introduction of

new capabilities with increased performance characteristics and reduced cost. However, this extra layer of device-independent protocol has the potential to reduce performance. A standard network interface would allow the connection of local networks and modems into the SSIS. Also, a standard program interface to the operating system would facilitate the portability of application programs. (There is an IEEE standard being developed for a Microprocessor Operating System Interface.)

Standard notations and languages would aid information and data exchange between different systems. A rigorous notation for display and dialog requirements will aid in designing the screen layout/interaction technique as well as verifying its completeness and adherence to established human factors guidelines. Standard data base query languages, programming languages, and a general user interface language to the Space Station system would provide consistency. Standard icons and ways of using them in the SSIS context could be formulated for use in graphically based systems.

At the application level, standards are necessary if programs are to share information. Standard ways of transferring data between applications should be specified, including protocols for file transfer and encryption across networks. Standard use of windows and other display/dialog techniques will maximize positive transfer of training between programs.

The Workstation As Translator

The scope of standardization may be limited by practical constraints to the NASA supported domain (such as CDOS). If this is the case, some form of translation at the boundary between the customer/user and NASA facilities will be required. One of the roles of the workstation could be to perform the function of translator by converting the data stream into a standard representation chosen to aid in monitoring selected elements and to restore compressed data to a usable form.

Potential translation functions for the workstation include:

- The data base query language used at the user site may be translated to the query language at the remote host site where the data reside.
- Gateways may be used to translate one network protocol into another.
- Compilers could target tools to an environment other than the one where they were built. An expert system could utilize the information from another knowledge base and incorporate these data into its own corpus of knowledge.
- The user interface may translate conceptual user requests into the actual user interface language commands that are transmitted.

The Workstation As Expert Modeller

For standardization work to be successful, it must be built upon a solid understanding of all aspects of the element to be standardized. This implies a robust model capable of accommodating new developments without jeopardizing the integrity of existing models.

The types of devices and the interactions they allow must be defined in order for a virtual device interface to make optimal use of devices envisioned for the workstation. This is especially true for Space Station unique hardware such as six degree of freedom controllers. In addition to modelling the operational characteristics of hardware, a model should also be developed for optimum interconnection architecture. As previously discussed, a modular workstation requires a flexible architecture in order that different modules can be exchanged without incurring a decrement in performance. The necessary tradeoffs must be conducted to ensure that flexibility and performance are built into the communications networks, and strategies are developed for the best use of the available resources.

Effort should be devoted to identifying data requirements, especially in regard to the types of data expected and their use in conjunction with other sources of information. This will involve data transmission, storage organization, and retrieval from data bases. A model of storage organization, for instance, may allow standard query languages to be formulated and used. Research needs to be conducted to identify an effective means for graphical representation of data and control functions, which will involve human cognitive models for information representation and processing.

To adequately plan a user interface management system, a model is required for user interaction strategies. Once this is known, then recognition of user misconceptions (i.e., operating outside a known strategy) may be possible. If it is possible to classify human operations, then it should also be possible to model the rule organization strategy used by expert systems.

A good model for software design methodology is eagerly sought by the software community. Such a methodology would facilitate the production of consistent, understandable, and modifiable applications. Formalization should also take place in regard to testing, and execution of the software (especially if distributed processing is to be used). Distributed processing on different machines would require the specification and use of a virtual machine representation in order to carry out the processing.

The Workstation As Expert Assistant

With the appropriate model as a basis for extrapolation, truly expert systems capable of learning may become commonplace.

The workstation will then be able to function as an expert assistant. Although every application of the workstation begins to resemble an expert system, here are some immediate areas of interest:

- Interpretation
  - pattern recognition for data base search
  - voice recognition
  - a user interface management system (UIMS) which learns your style, providing defaults where they can be inferred
- Design and Planning
  - optimizing compilers for multiple instruction - multiple data (MIMD) machines
  - code generation and algorithm selection
  - optimizing video display requirements against bandwidth available
  - scheduling and conflict resolution for calendar resources
  - network control/resource allocation
  - produce design from data specifications and human factors guidelines
  - interface author suggests best screen/dialog design
  - map instrument output into telemetry stream
- Test and Analysis
  - automated tester for thorough checkout of software design, implementation, and modification
  - experiment analysis, i.e., did it perform as expected?
- Diagnosis and Repair
  - rearrangement of data base for optimal use based on most frequent type of access
  - compare interface design to existing systems, suggest alternatives where appropriate
  - discover user misconceptions and train as appropriate
  - generally, an expert system analyzes itself, optimizing and adding learned knowledge
- Prediction
  - predicting rate of resource consumption
  - anticipatory/predictive simulation
  - tracking and predicting performance of the user, initiating help at the appropriate times
- Monitoring
  - monitoring of real-time data
  - expert system to keep an eye on all the other expert systems, watch for misconception propagation.

The Workstation As An Information Resource

The workstation will be a source of information, which will be obtained both locally and through the query of remote data repositories. In addition to scientific data, it is interesting to note the amount of past and present data from the user that is required for performance analysis and prediction. The following is a list of items expected to be available for use by workstation applications and users:

- catalog of what is available, where and how to get to it
- online help
- current and past states for extrapolation to the future
- device drivers to swap in and out
- software modules from a program library
- standard on-board computer loads
- test routines
- display templates/dialog routines
- table of current display attributes
- human factors guidelines
- system rules/knowledge for expert system base
- user actions/misconceptions for performance statistics, learning
- dummy test data
- archived engineering, science and ancillary data.
- mission, experiment and crew schedules
- hardware, software, and interface specifications and requirements

The Workstation As Logistics Manager

The workstation system will be capable of managing the logistic resources of the on-orbit experiment. Logistic management includes on-orbit servicing, inventory control, and record keeping.

The Space Station program requires that on-orbit servicing be available to the customers. Servicing includes such activities as payload retrieval, fault detection, fault isolation to the orbital replacement unit (ORU) level, ORU removal/replacement, instrument exchange, and experiment replenishment. The Space Station will provide this servicing capability using EVA, OMV, attached manipulator arms, or built-in servicing. The workstation will be capable of interfacing with each of these servicing modes.

For EVA servicing the workstation will support the EVA crewperson by monitoring operations, simulating failure modes to support fault diagnosis and isolation, and conducting special tests of experiment status. The workstation will interface directly with the EVA portable workstation and will provide the EVA crewperson with expert consultation regarding experiment structures and operations.

In the situation where servicing is being conducted by the OMV or a fixed manipulator arm, the workstation will, in addition to the support role described for EVA, provide actual control of end effectors, actuators, sensors, and structures. This control will be effected in a manual mode, using supervisory control techniques, or using adaptive control where the control task is initially conducted manually and the computer assumes control as it learns the control laws requirements. Where built-in servicing is conducted, the workstation can monitor the status of the servicing operation and modify control laws based on observed outcomes.

Inventory control involves the management of spares (ORUs), on-orbit resupply, planned maintenance, and ORU expenditure prediction. Management of ORUs involves a warehousing capability so that units can be stocked, inventoried, and retrieved as needed. On-orbit resupply applies to the replenishment of expendables, consumables, and ORU's either directly to the experiment or to a central storage facility. The role of the workstation in on-orbit resupply is to identify, schedule and issue resupply requirements, monitor satisfaction of these requirements, and control the utilization of supplied items.

Planned maintenance includes logistic actions performed to expand the life of the experiment, such as preplanned removal and replacement, inspection, checkout, calibration, adjustment, refurbishment, and cleaning. The role of the workstation in planned maintenance will be to identify the need for such maintenance, schedule its accomplishment, and in some cases to actually control the maintenance actions.

ORU expenditure prediction subsumes the activities associated with projecting shortfalls in available spares and determining the lead time to replenish spares in stock. The workstation will support this activity by simulating the expenditure of ORU's and determining when stocks must be replenished.

Logistics record keeping involves maintaining an accounting of logistic support provided and a lessons learned file to facilitate future experiment planning and operations. The role of the workstation in logistics record keeping is essentially to create, classify, store and retrieve logistics data before, during, and after completion of the mission.

The Workstation As Nuts And Bolts

The actual hardware configuration of the workstation depends upon the functions the workstation is expected to perform. Modularity, real-time performance, and local storage needs are obvious driving forces. Other issues include:

- Recognition that proven software will migrate to hardware, by placing it in ROM, firmware, or on a chip via silicon compilers.
- System Architecture - Factors here are flexibility for modularity, and speed for real-time operations; emergence of dedicated graphics, communications busses and processors; and intelligent device controllers, such as SCSI for disks. In addition, designers should consider hardware support for context switching to make multi-tasking feasible, and provision of many megabytes, perhaps gigabytes, of RAM to support these processes. Specialized symbolic processing subsystems for AI may emerge.
- Input/Output - Key factors for input are naturalness and ease of use, plus operator feedback. The concerns for output should be on quality and speed. Issues in I/O devices include:

- selection of input devices -- voice, mouse, touch screen, special controllers
- output -- design and application of high resolution monitors and flat screen technology, as well as methods for displaying video and text simultaneously on monitor

- Communications - Salient features of workstation communications include adequate response time, large capacity, security, and flexibility. In addition, designers should consider the use of fiber optic local network for speed and user-supplied satellite links (i.e., their own dishes?)
- Storage -- Data storage will be a major concern for the workstation user. General issues include:
  - Gigabyte requirements (optical disk)
  - Removable format (magnetic tapes, disk or optical disk)
  - Storage of graphics, audio, video.

ISSUES AND CONCERNS

Many issues and concerns were raised during the workshop (and implied by the results) concerning 1) the functional authority and autonomy allowed in a remote workstation; 2) the exact products and services to be supplied by NASA; and 3) guarantees of system integrity and performance. This section enumerates those issues for which answers and responsibility are not clear at this time. It is expected that these issues will be resolved in the near future.

- Government Furnished Equipment
  - Do the users provide their own hardware, or must they use the provided and approved system NASA specifies?
  - Using their own systems may involve extra layers of protocol to ensure compatibility. What is the performance cost of this, and who provides the necessary translators?
  - What software will be provided?
  - How are the modular features broken out/established?
  - What is the performance penalty for not using a facility the user interface management system was built to accommodate?
  - How does the user interface management system architecture handle different configurations? (Must it be re-compiled, or is it dynamically restructured?)
- Real-time Command and Control
  - Can one assume that a remote site workstation could perform all command and control functions?
  - What must be done at a central facility?
  - Will real-time control of experiments be allowed/feasible from a remote site workstation?
  - What hardware and software needs to be verified/flight qualified for operational use? (How does this happen?)
  - What will guarantee the availability of connections and data rates needed for an experiment?

- Is the user responsible for finding out about schedule changes, or is NASA responsible for providing that information? (What happens when the user doesn't get the word?)
- Will there be a need to have command management at the workstation? That is, are only valid sequences allowed on the system network, or is filtering of requests done somewhere else?

- Distributed Processing
  - How is the user guaranteed performance of remote processes?
  - If the user is a node in a distributed network, how is he assured access to his own machine?
- Security
  - How can users safeguard the proprietary nature of his data as it passes through the system?
  - Is this a single or multi-user workstation?
- Information Access
  - Who is responsible/owns what data?
  - How does the user find out what and where information is available?
  - Is there an electronic mail system for the user to make requests, complaints?
  - What information can users download/have mailed to their system?
  - Will the user have interactive access to data bases and scheduling information, or does the user have to submit batch requests?
  - When would the user have/want the authority to update remote data base?
- Languages
  - Are all programming languages supported, or just one? Or is the burden on the user to interface specific application to the system?
  - Can users follow their own software development method, or must they learn NASA's? If a single standard is used, will automated verification tools be available?
  - If a single user interface language is to be used, how does the user incorporate experiment specific directives?
  - Will there be textual commands or pictorial icons?
  - Can the user make macros, use a shorthand notation?
  - Must the user have a high-resolution monitor?
  - Does the actual user create the user interface, or must an expert be brought in to do it?
  - Does the user design screen dialogs by doing/example, or must it be written in procedures type language?
  - If the user has the freedom to customize the user interface, how is the formation of dialects avoided -- interfaces which only one user understands?

WORKSTATION DEVELOPMENT PLAN

A product of the GSFC Space Station Workstation Technology Development Program will be a prototype workstation system configured to accommodate selected technology thrusts identified in the workshop. This prototype workstation system will include actual or simulated hardware, software and procedures to enable the simulation of selected scenarios of workstation applications. The workstation system will also include Space Station customers or users, and a critical research issue will address the optimum role of the human user in the workstation system operation. The specific steps to be conducted in developing the prototype workstation system and the full mission simulation program are described in the following sections.

- Step 1: Determination of Workstation Users' Characteristics
  User characteristics and requirements will be established and levels of capability, in terms of requirements, will be defined.
- Step 2: Determination of Workstation Functions
  An initial set of workstation system functions for the space science application was developed as an input to the workshop. These functions are depicted in Figures 1 through 5. The generic functional sequence will be expanded and refined as needed based on an analysis of Space Station Science and Application missions. The result of this effort will be a set of functions which are applicable to all missions for the workstation phases of: experiment definition; experiment development; experiment test and integration; experiment conduct; and experiment evaluation/data analysis.
- Step 3: Development of Scenarios
  A set of scenarios will be developed which represent the results of a modelling of workstation functional sequences under determined operational conditions. Operational conditions include time constraints, workload factors, alternate allocation of system functions to the human operator or to the machine, and other factors associated with the performance of specific functions which influence the complexity of the conduct of those functions. Scenarios will describe functional sequences at iteratively greater levels of detail. Scenarios will also focus on alternative allocations of functions to human or to automation, where such allocations form the basis for alternate roles of the human user in the system.
- Step 4: Identify Requirements by Scenarios
  Requirements for the workstation system will be identified and analyzed. System requirements will include: information requirements; performance requirements; decision requirements; support requirements; and interface requirements or requirements associated with the interface between the workstation and other Space Station system

elements. Workstation system requirements will initially be identified for the system as a whole and without consideration for the requirements attendant to each workstation subsystem. Once system level requirements have been identified, requirements will be identified by subsystem for each function and subfunction inherent in the scenario. Subsystems to be addressed include: the human operator or user, communications, input/output devices, software, data management, data storage, user interface language, simulation, training, command and control (including resource management), and facilities.

- Step 5: <u>Develop Workstation Design Concepts</u>
  Based on the set of scenario requirements for the system as a whole and for each workstation subsystem, alternate workstation design requirements will be developed. Design concepts will differ in terms of the specific implementation of workstation technologies for the conduct of scenario functions. Design concepts will be characterized by specific implementations of workstation technology to enable the completion of workstation functions and subfunctions.
- Step 6: <u>Conduct a Task Analysis for Each Scenario</u>
  A task analysis will be conducted for each scenario for each workstation system concept. This analysis will identify, for each workstation system concept, requirements associated with each scenario task allocated to human operator performance. It will also establish the roles of the user for functions allocated to automated performance, and will identify the tasks inherent in these roles. Task requirements will define system needs in terms of requirements identified for each operator/user in the scenario requirements analysis. Specific task requirements include: frequency of task performance; duration of performance; information processing required; decisions required; actions required to complete the task; potential errors expected in the performance of the task; effects of these errors; and operational/environmental factors which impact the productivity of the operator performing the task.
- Step 7: <u>Conduct Design Studies</u>
  Prior to the conduct of tradeoffs to select an optimal design concept, design studies will be conducted. These studies will support the development of concepts, identify strengths and weaknesses of specific concepts, and they will provide data on the performance of concepts on selected tradeoff criteria. Design studies will also involve simulations of activities of workstation subsystems for the purpose of developing subsystem prototypes.
- Step 8: <u>Conduct Tradeoffs</u>
  A set of tradeoff criteria will be developed based on workstation requirements and constraints and based on scenario requirements. The validity and applicability of criteria will be assessed in the conduct of design studies. Tradeoffs will be completed wherein the performance

of alternate design concepts on specific tradeoff criteria will be determined. A limited number of cost-effective concepts will be selected. These candidate concepts will be subjected to a more intensive evaluation through design studies, and an optimal concept will be selected.

- Step 9: <u>Selected Concept Prototype</u>
  The selected concept will be prototyped and demonstrated through the use of part-task and full-task simulations. These simulations will be based on the scenarios and scenario requirements. The prototype workstation system will include actual and simulated hardware and software at a level of fidelity necessary to enable a complete demonstration of workstation capabilities.

Appendix A

WORKSTATION DESIGN ISSUES

ADVANCED WORKSTATION WORKSHOP ISSUES

HARDWARE

1.0 Input Devices

1.1 Major Factors
- 1.1.1 Naturalness
- 1.1.2 Ease of use

1.2 Types
- 1.2.1 Controls/controllers
  - • Key
    - Redefinable soft key
    - Predefined function key
  - • Keypad
    - Numeric
    - Cursor Control
    - Editing
  - • Keyboard
    - Attached versus cordless/remote
      - -- Infrared remotes
    - Sequential
      - -- Single versus multiboards
      - -- Sole versus other devices
    - Simultaneous
      - -- Chordboard
    - DVORAK
    - Maltron curved
  - • Valuator
    - Rotary
    - Linear
    - Thumbwheel
  - • Other control
    - Hand/glove
    - Foot
    - Postural
    - Head/eye
- 1.2.2 Direct screen input
  - • Light pen/wand
  - • Touch sensitive screen
  - • Optical character reader
- 1.2.3 Analog input
  - • Joystick
    - Absolute
    - Velocity
  - • Trackball
  - • Exoskeleton
  - • Stylus on tablet
    - Dynamic character recognition
  - • 3D Ultrasonic wand
  - • Sensors
    - Video camera
  - • Image processor

- Mouse
  - Digital
  - Optical
  - Mechanical
  - Optical - mechanical
- Robot vision

1.2.4 Voice

- Speech recognition
  - Types
    - -- Speaker dependent versus independent
    - -- Connected versus unconnected speech
  - Systems
    - -- Augmented transition network
    - -- Lisner 1000
    - -- Verbox/Exxon series 4000
    - -- Smooth talker
- Speech synthesis
  - Text-to-speech
    - -- Computer with a voice
    - -- Terminal with a voice
    - -- Voice response telephone
    - -- DEC #talk unit
- Linear predictive coding
  - General Instrument SP-250, 256
  - TI TMS 5220
  - American Microsystems 53620
- Combined videotex - audiotex systems
- Voice/data remote information stations
  - Liberty Electronics Freedom 212 Remote Station
- Language translation units

2.0 Output Devices

2.1 Major Factors

2.1.1 Quality

2.1.2 Speed

2.2 Types

2.2.1 Visual displays

- Permanent record
  - Printer
    - -- Technology
      - --- Inkjet
      - --- Laser
    - -- Capabilities
      - --- Text
      - --- Symbolic
      - --- Graphic
      - --- Pictorial
  - Plotter
    - -- Capabilities
      - --- Symbolic
      - --- Graphic
      - --- Pictorial

- Stripchart recorder
- Photograph
- Videotape/disc

● Transient display
- Monitor
  -- Features
    --- Resolution
    --- Flicker
    --- Size
    --- Color
  -- Technology
    --- CRT
      ---- Raster scan
        ----- Microdot/pixel phasing
      ---- Vector
    --- Liquid Crystal (LCD)
      ---- Twisted-nematic field effect
      ---- Active matrix of thin-film transistors
      ---- Smectic
      ---- Dye-based phase change
    --- Light emitting diode (LED)
    --- Electroluminescent
      ---- thin-film
      ---- powder
    --- Vacuum florescent
    --- Plasma
      ---- AC
      ---- DC
      ---- AC-DC hybrid
      ---- Gas-electron-phosphor
- Large screen projection
- Three-dimensional
  -- Holography
  -- Stereoscopic video
  -- Projection stereo
- Heads up displays
- Light coding - patterns

● Touch-tactic displays
- Pressure point
- Pattern points
- Vibration

● Auditory displays
- Real time
  -- Discrete signals
  -- Continuous signals
  -- Voice display
- Recorded

3.0 Storage

3.1 Major Factors

3.1.1 Access time

3.1.2 Capacity

3.2 Tape
  3.2.1 Streaming
  3.2.2 Video

3.3 Disk
  3.3.1 Winchester
    - Optical
  3.3.2 Removable
    - Floppy
      - 5.25"
    - Rigid
      - 3.5"
      - Audio compact disc
      - Video disc

3.4 Cartridge
  3.4.1 ROM
  3.4.2 Bubble Memory
  3.4.3 Bernoulli box

4.0 System Architecture

4.1 Major Factors
  4.1.1 Speed
  4.1.2 Flexibility

4.2 Single, Central Processing Unit (full 32-bit path width)

4.3 Dedicated Special Purpose Processors
  4.3.1 Floating point processor
  4.3.2 Array processor (pipelining)
  4.3.3 Text display controller
  4.3.4 Graphics display controller
    - Silicon graphics geometry engine
    - Privac CT-1000 chip
    - NAPLPS decoder
  4.3.5 Pattern recognition
    - Proximity filter PF 474
  4.3.6 Robotic devices
    - Manipulators
    - Remote vision

4.4 Memory Management
  4.4.1 Paging (virtual memory support)
  4.4.2 Garbage collection
  4.4.3 Table lookaside buffer
  4.4.4 Cache

4.5 Intelligent Device Controller
  4.5.1 Disk
  4.5.2 Communications/network-transputer

4.6 Main Memory
  4.6.1 Capacity
  4.6.2 Video display frame buffer

- 4.7 Internal Bus Structure
    - 4.7.1 Topology
        - Single bus
        - Multiple buses
        - Direct memory access
    - 4.7.2 Signal protocol
        - Asynchronous
        - Synchronous
    - 4.7.3 Orientation
        - Byte
        - Block

- 4.8 Interrupt Handling
    - 4.8.1 Hierarchical
    - 4.8.2 Vectored

- 4.9 Parallelism

- 4.10 Distributed Multi-processing/Interprocessor Communication

- 4.11 Small Computer System Interface (ANSI X3T9.2)

5.0 Communications

- 5.1 Major Factors
    - 5.1.1 Response time
    - 5.1.2 Capacity
    - 5.1.3 Security
    - 5.1.4 Geographic constraints

- 5.2 Interface Component
    - 5.2.1 Broadcast receiver/transmitter
        - FM radio
        - Microwave
        - Infrared
        - Satellite
    - 5.2.2 Modems
        - Asynchronous
            - RS-232C
            - RS-449
        - Synchronous
    - 5.2.3 Network interface unit
        - RS-442
        - V.35

- 5.3 Gateways

- 5.4 Networks
    - 5.4.1 Category
        - Local area network
        - High-speed local network
        - Digital PABX
        - Wide area network
    - 5.4.2 Topology

- Bus/tree
- Ring
- Star

5.4.3 Media
- Twisted copper pair (- 5 Mb/s)
- Coaxial cable (- 50 Mb/s)
- Fiber optic (- 1 Gb/s)

5.4.4 Transmission technique
- Baseband (- 50 Mb/s)
- Broadband (- 400 Mb/s)

5.4.5 Switching technique
- Packet
- Message
- Circuit

5.4.6 Protocol
- Asynchronous
- Bisynchronous - IBM
- SNA/SDLC
- DECNET - DEC
- XNS - Xerox ethernet
- TCP/IP - ARPAnet
- X.25 - GTE telenet

5.4.7 Access method
- Centrally controlled/synchronous
- Distributed/asynchronous
  - Deterministic/fixed access
    - Token passing
    - Collision avoidance
  - Random/open access
    - Carrier sense multiple access with collision detection
    - Register insertion
    - Slotted ring

5.4.8 Examples
- Digital PABX
  - Star
  - Twisted pair
  - Circuit switched
  - Centrally controlled
- AT&T circuit switched digital capability (-56 Kb/s)
- CATV
  - Coaxial
  - Broadband
  - RS-170
- Ethernet
  - Bus
  - Triaxial
  - Baseband
  - XNS
  - CSMA/CD (10 mb/s)

5.9 Types of Information Transmitted

5.9.1 Text-data

5.9.2 Images

5.9.3 Speech

5.9.4 Graphics

6.0 Terminals

6.1 Intelligent Terminal
- 6.1.1 Device intelligent
- 6.1.2 Host intelligent

6.2 Color Graphics Terminal
- 6.2.1 Local storage
- 6.2.2 Response time/speed of drawing

6.3 Portable Computers
- 6.3.1 Movable - stationary
- 6.3.2 Handheld

SOFTWARE

1.0 Display Processing

1.1 Intraframe
- 1.1.1 Symbol/character generators
- 1.1.2 Frame organization
  - Fixed
  - Variable (software selected)
  - Variable (user selected)
  - Page format

1.2 Interframe
- 1.2.1 Frame sequencing
  - Paging/scrolling
  - Overlapping
  - Branching

2.0 System Interaction Techniques

2.1 Menu Processing

2.2 Form-filling

2.3 Question and Answer

2.4 Command Language

2.5 Function Keys

2.6 Interactive Voice

2.7 Interactive Graphics

2.8 Natural Language

2.9 Objects/icons

3.0 Graphics

3.1 Processing
- 3.1.1 Clipping
- 3.1.2 Scan-conversion
- 3.1.3 Anti-aliasing
- 3.1.4 Region filling
- 3.1.5 Shading
- 3.1.6 Hidden line/surface removal
- 3.1.7 Segmentation
- 3.1.8 Color control
- 3.1.9 Draw
- 3.1.10 Move
- 3.1.11 Zoom
- 3.1.12 Pan

3.1.13 Scroll
3.1.14 Windowing
3.1.15 Fractals
3.1.16 Polygonization
3.1.17 Capping
3.1.18 Texture processing
- Mapping
- Fractals

3.1.19 Imaging
- Laser animation
- Free-hand drawing

3.2 Mix with Video

3.3 Protocols
3.3.1 · GKS
3.3.2 NAPLPS
3.3.3 IGES
3.3.4 PHIGS

4.0 Integrated Software (graphics and text)

4.1 Examples
4.1.1 Symphony
4.1.2 Aura
4.1.3 Framework

5.0 Expert Systems/Artificial Intelligence

6.0 System Integration

6.1 Windows
6.1.1 Single application
6.1.2 Integrated

6.2 VDI & VDM

6.3 Operating System

7.0 System Facilities

7.1 Word processing

7.2 Electronic mail/bulletin board

7.3 Management information system

7.4 Decision support system

7.5 Database management system
7.5.1 Query language

7.6 User interface management system

7.7 Schedule/project tracking

7.8 Calendar

7.9 Tutorial

7.10 Online documentation

8.0 Programming Support Tools

- 8.1 Requirements Analysis

- 8.2 Program Design
  - 8.2.1 Data flow and process diagrams

- 8.3 Prototyping

- 8.4 Coding
  - 8.4.1 Languages
  - 8.4.2 Syntax-directed editor
  - 8.4.3 Software library manager

- 8.5 Symbolic Debugging
  - 8.5.1 Static analysis
    - Cross-reference generator
  - 8.5.2 Dynamic analysis
    - Path decomposition and coverage
  - 8.5.3 Program instrumentation
    - Trace
    - Breakpoint setting
  - 8.5.4 Regression testing
- 8.6 Maintenance
  - 8.6.1 Source version control

- 8.7 Performance Analysis
  - 8.7.1 Modelling and simulation

Appendix B

SPACE SYSTEM DATA MANAGEMENT SYSTEM REQUIREMENTS

SPACE SYSTEM DATA MANAGEMENT SYSTEM REQUIREMENTS

Specific requirements for the Space Station Data Management System (DMS) are:

- Data partitioning and protection to accommodate data privacy and security.
- The DMS shall support data base access, command and control, data transmission, computer, and workstation resources for DMS users and Station subsystems.
- The DMS shall enable on-line capabilities such as command data processing, program generation and debug word processing, graphics, electronic mail, health monitoring imaging for proximity operations, display of performance and trend data, subsystem performance and payload interface monitoring.
- The DMS shall support a user-friendly language for man-machine interface. The language shall be capable of interfacing between man and machine for communications, display generation, monitoring, checkout and control during all phases of development and operations.
- The operational interface to the DMS shall be through Multipurpose Applications Consoles (MPAC). The MPAC shall be a common design functioning as a man-machine interface to the network operating system.
- The MPAC shall provide command and control, monitoring, operations, training capabilities, visibility into all subsystems, simultaneous viewing of displays, and caution and warning capabilities.

- <u>Space Station Communications and Tracking</u>.

  The communications and tracking system shall provide for the transmission, reception, digitization,

distribution, signal processing and controlling of audio, telemetry, commands, user data, science data, computer data, video text and grahics. Specific capabilities to be provided for communications and tracking are:

- Multiple duplex voice channels between the Station and ground facilities and the capability to record, process, amplify, mix, recognize, synthesize, switch and distribute voice and audio to and from all internal locations and provide voice conferencing capability between orbital elements and the ground.
- Communications between the ground and the Space Station shall be through the Tracking and Data Relay Satellite (TDRS) or its replacement system.
- The design shall provide for acquisition, signal processing, distribution, and transmission of customer data. Flight and ground data systems supporting payloads shall be transparent to the customer.
- The design shall allow crew members to communicate privately with the ground via audio and video.
- Payload operations at the Station and within the Space Station Program shall include the capability for a high level of customer participation and responsibility, including independent customer operation and monitoring of payloads.
- The capability will be provided to allow users to remotely command, control, monitor, throughput, and preprocess data for their elements.
- Operations involving experiments and payloads shall place a minimum of simple, standard, and stable constraints on customers.
- The information and data management services shall provide data storage, processing, presentation, and

transmission services adequate to accommodate the customer requirements. Access to the services shall be provided through standard network interface nodes and workstations.

Appendix C

TECHNOLOGY FORECAST WORKSHEETS

- Function 1.0 - Experiment Definition
- Subfunction 1.3 - Access Special Data Bases
- Scenario: In defining the experiment, an experimenter will require access to data bases containing results of other investigations of the phenomenon of interest. The data management system inherent in the workstation must be able to identify those relevant data bases, access and retrieve data, compile, correlate and process these data and display the results to the experimenter.

Workstation Capabilities	Technology Forecasts

A-1.1 - Network Typology Configuration:

A-1.3 - Teleconferencing:

A-2.4 - Electronic Mail:

B-2.2 - Interface with Special Data Bases:

B-3.1 - Local Data Base Management:

Other:

- Function 1.0 - Experiment Definition
- Subfunction 1.7 - Conduct Experiment Simulation
- Scenario: During the definition of the experiment, the scientist will be provided the capability of modeling the experiment and simulating the selection of targets of interest, conduct of experimental procedures, and handling of experiment data.

Workstation Capabilities	Technology Forecasts
A-2.1 - Communications Mode Control:	
B-3.4 - Control of Simulation/Training:	
D-3.1 - Simulation Program Processing Tools:	
D-3.2 - Dummy Data Generation:	
Other:	

- Function 1.0 - Experiment Definition
- Subfunction 1.11 - Develop Experiment Plan and Schedule
- Scenario: Having identified data requirements, conducted simulations, and defined experiment strategies, the experimenter will develop a plan and schedule for the experiment. The workstation should provide software, displays and overall mission constraints to support this planning process.

<u>Workstation Capabilities</u>	<u>Technology Forecasts</u>
D-6 - Planning Aids:	
C-1.4 - Integrated Display:	
C-1.7 - Decision Aids:	
Other:	

- Function 2.0 - Experiment Development
- Subfunction 2.4 - Develop Display Format Requirements
- Scenario: The experimenter will identify the specific displays required for the conduct and management of the experiment, and will determine the display mode and format of each display. The workstation will allow the experimenter to try out alternate formats, and will provide dummy data for display format generation. The workstation will also enable the experimenter to identify which formats should be fixed and which should be variable, and to establish the limits of format variability.

<u>Workstation Capabilities</u>	<u>Technology Forecasts</u>

A-1.2 - Security/Privacy:

C-1.4 - Integrated Display:

C-4 - User Interface Language:

D-1.3 - Dialogue Generation Tools:

D-2.1 - Display Processing Tools:

Other:

- Function 2.0 - Experiment Development
- Subfunction 2.5 - Develop Commands
- Scenario: The experimenter will identify the commands required for experiment control and management. The workstation will provide capabilities for command generation in real time and maintenance of a command inventory.

Workstation Capabilities	Technology Forecasts
A-1.1 - Typology Configuration:	
A-1.2 - Security/Privacy:	
A-2.1 - Communications Mode Control:	
A-2.2 - Message Transmit/Receive:	
C-1.5 - Feedback Display:	
C-4 - User Interface Language:	
D-1.2 - Command Generation:	
G-5 - Command Management:	
Other:	

- Function 2.0 - Experiment Development
- Subfunction 2.7 - Develop Embedded Training
- Scenario: The workstation will be capable of training operators through use of workstation hardware and software in a training mode. This training capability should consist of, at a minimum, a method for simulating experiment operation to provide for practice of operations, access to external simulations, and methods to measure operator performance.

Workstation Capabilities	Technology Forecasts
A-2.1 - Communications Mode Control:	
B-3.4 - Control of Simulation/Training:	
C-4 - User Interface Language:	
D-3 - Simulation and Training Development:	
Other:	

- Function 2.0 - Experiment Development
- Subfunction 2.8 - Develop Control Laws
- Scenario: The experimenter will identify the mode by which control over experiment activities will be exerted, i.e., manual, supervisory or automated control. Control laws as they apply to each control requirement will either be generated or will be selected from an already existing library of control laws.

<u>Workstation Capabilities</u> <u>Technology Forecasts</u>

A-4 - Communication Interface Standards:

B-1.1 - Space Systems Operation:

B-1.2 - Experiment Servicing:

B-1.3 - Direction of Mission Specialists:

C-1.5 - Feedback Display:

C-4 - User Interface Language:

Other:

- Function 2.0 - Experiment Development
- Subfunction 2.9 - Develop Interactive Dialogues
- Scenario: The experimenter will identify interactions between user and workstation and will develop/select interactive dialogues to accomplish these interactions. The workstation will support the selection, development, and implementation of interactive dialogues.

<u>Workstation Capabilities</u>	<u>Technology Forecasts</u>

A-1.3 - Teleconferencing:

A-2.4 - Electronic Mail:

B-3.2 - Memory Control:

B-3.3 - Documentation Control:

C-2 - Human-Computer Dialogues:

C-2.1 - Data Entry:

C-2.2 - Data Access/Retrieval:

C-2.3 - Data Designation/Manipulation:

C-2.4 - Data Edit/Verification:

C-4 - User Interface Language:

D-1.3 - Dialogue Generation:

Other:

- Function 2.0 - Experiment Development
- Subfunction 2.10 - Develop Software
- Scenario: The workstation will provide the capability to identify software requirements, develop software architectural structure, generate software, maintain and debug software, and measure software performance.

<u>Workstation Capabilities</u>	<u>Technology Forecasts</u>
B-3.3 - Documentation Control:	
C-3 - Procedures:	
D-4 - Software Development Tools:	
D-4.1 - Programming:	
D-4.2 - Debugging:	
D-4.3 - Software Update:	
D-5 - Data Handling and Analysis Tools:	
D-6 - Planning Aids:	
Other:	

- Function 2.0 - Experiment Development
- Subfunction 2.10 - Develop Software
- Scenario: The workstation will provide the capability to identify software requirements, develop software architectural structure, generate software, maintain and debug software, and measure software performance.

<u>Workstation Capabilities</u>	<u>Technology Forecasts</u>

B-3.3 - Documentation Control:

C-3 - Procedures:

D-4 - Software Development Tools:

D-4.1 - Programming:

D-4.2 - Debugging:

D-4.3 - Software Update:

D-5 - Data Handling and Analysis Tools:

D-6 - Planning Aids:

Other:

- Function 3.0 - Experiment Test and Integration
- Subfunction 3.8 - Conduct Training
- Scenario: Training of workstation operators will be conducted at the workstation using embedded training techniques. The training technique will measure trainee performance and will either qualify the trainee as an operator or present the trainee with additional instruction.

Workstation Capabilities	Technology Forecasts
B-3.4 - Simulation/Training Control:	
C-3 - Procedures:	
C-4 - User Interface Language:	
D-7 - Testing Aids:	
Other:	

- Function 3.0 - Experiment Test and Integration
- Subfunction 3.9 - Verify Experiment Readiness
- Scenario: The experimenter will conduct tests and checkouts of command links, telemetry links, communication and experiment systems. The workstation will be capable of conducting compliance tests and system status tests, and conducting operator training.

Workstation Capabilities	Technology Forecasts
A-1.4 - Network Readiness Monitoring:	
B-1.2 - Experiment Servicing:	
B-3.4 - Control of Simulation/Training:	
C-1.3 - Status/Ancillary Data Display:	
C-1.6 - Alarm/Alert Display:	
D-2.3 - Computer Aiding:	
D-5 - Data Handling and Analysis Tools:	
D-7 - Testing Aids:	
E-2.1 - Performance Monitoring:	
E-2.2 - Data Quality Checking:	
Other:	

- Function 4.0 -- Conduct Experiment On-Orbit
- Subfunction 4.2 - Receive and Process Telemetry Data
- Scenario: The workstation will receive and process data for the telemetry link to orbiting spacecraft, and from network control elements.

<u>Workstation Capabilities</u>	<u>Technology Forecasts</u>
A-1.2 - Security/Privacy:	
A-2.2 - Message Transmit/Receive:	
A-2.4 - Electronic Mail:	
A-5 - Communication Interface Standards:	
B-1.4 - Interface with Data Archives:	
B-3.1 - Local Data Base Management:	
C-1.1 - Real Time Data Display:	
C-1.2 - Delayed Data Display:	
C-1.4 - Integrated Display:	
C-1.7 - Decision Aids:	
C-2.3 - Data Designation/Manipulation:	
D-2.1 - Display Processing:	
E-1 - SSIS Interface Management:	
Other:	

- Function 4.0 - Conduct Experiment On-orbit
- Subfunction 4.4 - Generate Commands
- Scenario: The workstation will provide command generation tools and the capability to store/retrieve commands as well as generate commands in real time.

Workstation Capabilities	Technology Forecasts
A-1.1 - Typology Configuration:	
A-3 - Tracking and Pointing:	
B-1.3 - Experiment Servicing:	
C-1.5 - Feedback Display:	
C-4 - User Interface Language:	
D-1.2 - Command Generation:	
E-5 - Command Management:	
Other:	

- Function 4.0 - Conduct Experiment On-orbit
- Subfunction 4.5 - Conduct Quick Look
- Scenario: The workstation will select and process data for direct display for the purpose of providing a quick look to support selection of experiment sequences, selection of targets, and/or to ensure that critical data points are processed in the event of experiment or link failure.

Workstation Capabilities	Technology Forecasts
A-2.4 - Electronic Mail:	
B-1.2 - Experiment Servicing:	
C-1.1 - Real Time Data Display:	
C-1.4 - Integrated Display:	
C-2.3 - Data Designation/Manipulation:	
C-4 - User Interface Language:	
D-2.1 - Display Processing:	
Other:	

- Function 4.0 - Conduct Experiment On-orbit
- Subfunction 4.7 - Monitor Experiment Operations
- Scenario: The workstation will provide capability to monitor on-going experiment operations, verify the status of the experiment, verify data quality, detect and isolate faults, and identify data problems.

<u>Workstation Capabilities</u>	<u>Technology Forecasts</u>
A-1.4 - Network Readiness Monitoring:	
B-1.2 - Experiment Servicing:	
C-1.1 - Real Time Data Display:	
C-1.2 - Delayed Data Display:	
C-1.3 - Status Data Display:	
C-1.4 - Integrated Display:	
C-1.6 - Alarm/Alert Display:	
C-3 - Procedures:	
C-4 - User Interface Language:	
D-7 - Testing Aids:	
E-2 - Service Assurance:	
E-6 - Resources Management:	
Other:	

- Function 4.0 - Conduct Experiment On-orbit
- Subfunction 4.10 - Conduct Experiment Servicing
- Scenario: The workstation will enable the servicing of experiment payload instruments, apparatus and equipment, including changeout and calibration, resupply, replenishment, refurbishment, inspection, repair, adjustment, deployment and retrieval.

Workstation Capabilities	Technology Forecasts
B-1.2 - Experiment Servicing:	
D-7 - Testing Aids:	
E-2.1 - Performance Monitoring:	
E-3 - Safing:	
E-4 - Degraded Mode Operations:	
Other:	

- Function 4.0 - Conduct Experiment On-orbit
- Subfunction 4.13 - Develop Special Software
- Scenario: During the conduct of the experiment requirements may be encountered for the generation of software on the modification of existing software. The workstation will provide the capability for special software development and verification.

<u>Workstation Capabilities</u>	<u>Technology</u>
C-4 - User Interface Language:	
D-4.1 - Programming:	
D-4.2 - Debugging:	
D-4.3 - Software Update:	
D-5 - Data Handling and Analysis Tools:	
Other:	

- Function 4.0 - Conduct Experiment On-orbit
- Subfunction 4.14 - Conduct Simulation
- Scenario: During the conduct of the experiment simulations will be required to assess alternate operational sequences in the event of changes in experiment priorities, equipment status or data quality. The workstation will provide the capability of conducting simulations including use of hi-fi external simulations, and communicating the results to the on-board payload specialist(s).

Workstation Capabilities	Technology Forecasts
B-3.4 - Control of Simulation/Training:	
D-3.1 - Simulation Program Processing Tools:	
D-3.2 - Dummy Data Generation:	
Other:	

- Function 5.0 - Experiment Evaluation/Data Analysis
- Subfunction 5.7 - Data Analysis
- Scenario: Data analysis will be conducted throughout experiment operations and after experiment termination to reduce and correlate data and perform analytical test functions.

Workstation Capabilities	Technology Forecasts
B-3.1 - Local Data Base Management:	
D-2.2 - Report Processing:	
D-5 - Data Handling and Analysis Tools:	
D-7 - Testing Aids:	
E-2.2 - Data Quality Checking:	
Other:	

- Function 5.0 - Experiment Evaluation/Data Analysis
- Subfunction 5.16 - Evaluate the Experiment/Data Quality
- Scenario: Experiment evaluation will be conducted throughout experiment operations and after the experiment is completed to evaluate experiment system performance, and to evaluate data quality.

<u>Workstation Capabilities</u> <u>Technology Forecasts</u>

A-1.4 - Network Readiness Monitoring:

B-2.1 - Interface with SSIS, SSDS, and TMIS:

B-3.1 - Local Data Base Management:

D-2.2 - Report Processing:

D-5 - Data Handling and Analysis Tools:

D-7 - Testing Aids:

E-2.1 - Performance Monitoring:

E-2.2 - Data Quality Checking:

E-7 - Service Accounting:

E-8 - Record Keeping:

Other:

- Function 5.0 - Experiment Evaluation/Data Analysis
- Subfunction 5.17 - Prepare Reports
- Scenario: At the termination of the experiment, or at a milestone point in an extended experiment, the experimenter will prepare a report citing principal findings, lessons learned, and unanswered questions. The workstation will support the report preparation through word processing, documentation development, and cancelation of findings with the state-of-knowledge.

Workstation Capabilities	Technology Forecasts
A-1.2 - Security/Privacy:	
A-2.3 - Data Dissemination:	
B-1.4 - Access to data archives:	
B-2.1 - Interface with SSIS, SSDS, TMIS:	
B-3.3 - Documentation Control:	
D-2.2 - Report Processing Tools:	
E-7 - Service Accounting:	
E-8 - Record Keeping:	
Other:	

Appendix D

WORKSHOP PARTICIPANTS
and their
ORGANIZATIONAL AFFILIATION

WORKSHOP PARTICIPANTS
and their
ORGANIZATIONAL AFFILIATIONS

Mr. Curtis Barrett
NASA
Goddard Space Flight Center
Code 735
Greenbelt, Maryland 20771
301-344-5203

Dr. Deborah Boehm-Davis
George Mason University
Department of Psychology
4400 University Drive
Fairfax, VA 22030
703-323-2203

Dr. Randall M. Chambers
U. S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, Virginia 22339
703-274-8905

Mr. Jay Costenbader
NASA
Goddard Space Flight Center
Code 522
Greenbelt, Maryland 20771
301-344-1177

Mr. Randall L. Davis
University of Colorado
Laboratory for Atmospheric Space
Campus Box 392
Boulder, Colorado 80309
303-492-6867

Dr. Ray E. Eberts
Purdue University
262 Grissom Hall
Industrial Engineering Department
West Lafayette, Indiana 47907
317-494-5400

Mr. David R. Eike
Carlow Associates Incorporated
8315 Lee Highway
Fairfax, VA 22031
703-698-6225

Mr. Curtis Emerson
NASA
Goddard Space Flight Center
Code 522
Greenbelt, Maryland 20771
301-344-5149

Mr. Jack J. Hatfield*
Mail Stop 494
NASA
Langley Research Center
Hampton, VA 23665
804-865-2171

Mr. Christopher C. Heasly
Carlow Associates Incorporated
8315 Lee Highway
Fairfax, Virginia 22031
703-698-6225

Dr. Michael G. Joost
Industrial Engineering Department
North Carolina State University
P.O. Box 5511
Raleigh, N.C. 27650
919-737-2362

Dr. Mark Kirkpatrick
Carlow Associates Incorporated
8315 Lee Highway
Fairfax, Virginia 22031
703-698-6225

Mr. Walter H. Kopp
Carlow Associates Incorporated
8315 Lee Highway
Fairfax, Virginia 22031
703-698-6225

Dr. Jill H. Larkin*
Carnegie Mellon University
Psychology Department
327-L Baker Hall
Pittsburgh, PA 15213
412-578-3785

Mr. Edward Lowe
NASA
Goddard Space Flight Center
Code 501
Greenbelt, Maryland 20771
301-344-5027

Ms. Mary T. Malone
Carlow Associates Incorporated
8315 Lee Highway
Fairfax, Virginia 22031
703-698-6225

Dr. Thomas B. Malone
Carlow Associates Incorporated
8315 Lee Highway
Fairfax, Virginia 22031
703-698-6225

Capt. Bruce McCandless
NASA
Johnson Space Center
NASA Road 1
Houston, Texas 77058
713-483-2321

Dr. Doyle McDonald
NASA
Headquarters
Code SUU
Washington, D.C. 20546
202-453-8658

Dr. Christine M. Mitchell
ISE
Georgia Institute of Technology
Industrial and Systems Engineering
Atlanta, GA 30332
404-894-4321

Ms. Karen Moe
NASA
Goddard Space Flight Center
Code 522
Greenbelt, Maryland 20771
301-344-5292

Mr. Larry Morgan
NASA
Code DE-DED-22
Kennedy Space Flight Center
Florida 32899
305-867-4430

Dr. Anthony Norcio*
Code 7592
Naval Research Laboratory
Washington, D. C. 20375-5000
202-767-2953

Dr. Kent L. Norman
Room 2123F
Zoology/Psychology Building
University of Maryland
College Park, MD 20742
301-454-6388

Mr. Larry Novak
NASA
Goddard Space Flight Center
Code 635
Greenbelt, Maryland 20771
301-344-9534

Dr. John J. O'Hare
Science Office
Engineering Psychology Program
U. S. Navy
Office of Naval Research
800 North Quincy Street
Code 442
Arlington, VA 22217
202-696-4502

Dr. Dan R. Olsen
217 TMCB
Brigham Young University
Provo, Utah 84602
801-378-3027

Dr. Everett A. Palmer
NASA
Ames Research Center
Mail Stop 239-3
Moffett Field, California 94035
415-965-6147

Ms. Dorothy C. Perkins
NASA
Goddard Space Flight Center
Code 522
Greenbelt, Maryland 20771
301-344-5069

Mr. Larry Peterson
U. S. Army
Human Engineering Laboratory
Building 520
Attn: DRXHE-CC
Aberdeen Proving Ground, MD 21005
301-278-5962

Mr. Michael Rackley
NASA
Goddard Space Flight Center
Code 522
Greenbelt, Maryland 20771
301-344-5753

Dr. Marianne Rudisill
NASA
Johnson Space Flight Center
NASA Road 1
Mail Code SP
Houston, Texas 77058
713-333-6148·

Dr. John L. Sibert
Elec. Eng./Computer Sciences Dept.
Academic Building
Room 624B
George Washington University
Washington, D. C. 20052
202-676-4953

Dr. Harry L. Snyder
VPI&SU
IEOR Department
130 Whittemore Hall
Blacksburg, VA 24061
703-961-7527

Ms. Martha Szczur
NASA
Goddard Space Flight Center
Code 365
Greenbelt, Maryland 20771
301-344-9425

Mr. Steven Tompkins
NASA
Goddard Space Flight Center
Code 511
Greenbelt, Maryland 20771
301-344-6791

Mr. Walter Truszkowski
NASA
Goddard Space Flight Center
Code 522
Greenbelt, Maryland 20771
301-344-8821

Mr. C. W. Vowell
NASA
Johnson Space Flight Center
Code FS13
Houston, Texas 77058
713-483-5169

Dr. Mark Weiser
Department of Computer Science
University of Maryland
College Park, Maryland 20742
301-454-7817

Mr. A. Wetterstroem
NASA
Johnson Space Flight Center
Code EF2
Houston, Texas 77058
713-483-2313

Dr. Kelli Willshire
NASA
Headquarters
Code SEM
Washington, D. C. 20546
202-453-1167

Dr. Dana Yoerger
Woods Hole Oceanographic Institute
Woods Hole, MA 02543
617-548-1400

*Did not participate in Workshop

1. Report No. NASA CP-2414	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SPACE STATION WORKSTATION TECHNOLOGY WORKSHOP REPORT		5. Report Date April 1986
		6. Performing Organization Code 522
7. Author(s) Karen L. Moe, Curtis M. Emerson, David R. Eike, and Thomas B. Malone		8. Performing Organization Report No. 4033-85-1DRE
9. Performing Organization Name and Address Data Systems Applications Branch Mission Operations and Data Systems Directorate Goddard Space Flight Center Greenbelt, MD 20771		10. Work Unit No. 86B0098
		11. Contract or Grant No. NAS5-28597
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered
		14. Sponsoring Agency Code 522

15. Supplementary Notes

David R. Eike and Thomas B. Malone are with Carlow Associates, Fairfax, VA

16. Abstract

This report describes the results of a workshop conducted at Goddard Space Flight Center (GSFC) to identify current and anticipated trends in human-computer interface technology that may influence the design or operation of a Space Station workstation. The workshop was attended by approximately 40 persons from goverment and academia who were selected for their expertise in some aspect of human-machine interaction research. The focus of the workshop was a 1 ½ day brainstorming/forecasting session in which the attendees were assigned to interdisciplinary working groups and instructed to develop predictions for each of the following technology areas: 1) user interface, 2) resource management, 3) control language, 4) data base systems, 5) automatic software development, 6) communications, 7) training, and 8) simulation. This report is significant in that it provides a unique perspective on workstation design for the Space Station. This perspective, which is characterized by a major emphasis on user requirements, should be most valuable to Phase B contractors involved in design and development of the Space Station workstation. One of the more compelling results of the workshop is the recognition that no major technological breakthroughs are required to implement the current workstation concept. What is required is the creative application of existing knowledge and technology.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Space Station, Human Factors, Workstation, User-computer Interface, Human-computer Interface	Unlimited – Unclassified Subject category 17

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
UNCLASSIFIED	UNCLASSIFIED	124	A06

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1986

National Aeronautics and
Space Administration
Code NIT-4

Washington, D.C.
20546-0001